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STAFF REPORT

Wind Energy in California

2014 Description, Analysis, and Context

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ABSTRACT

This report is the first addressing the state of wind energy in California since reinstatement of the California Energy Commission's Wind Performance Reporting System in 2014. It presents data and information including, but not limited to, wind generator locations, groupings in areas such as designated wind resource areas, sizes both in numbers and generating capacities, the amount of electricity wind facilities generated in 2014 and when, and related physical properties.

This document provides useful data and information about California's wind generation. The information is based on a robust data collection method that provides users with a product that can be relied upon. The data underlying the information are publicly available for examination and use.

In addition to presenting customary data and information, such as wind capacities and generation, staff presents a comparison of wind resource areas using correlation techniques. This approach verified some presumptions about the areas but also challenged other presumptions, leading to questions that future reports may pursue.

Keywords: Wind capacity, generation, resource areas, capacity factors, correlation coefficient, Pearson method, energy purchases

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EXECUTIVE SUMMARY

California is one of the leading states in wind generation in the United States. This report provides a comprehensive set of information concerning the status of wind energy in California during 2014, the first year in a decade with complete information on the subject.

Knowing the status of California's wind energy resources is useful to a variety of people and organizations. The California Energy Commission's recently reinstituted Wind Performance Reporting System (WPRS) program is a primary source of wind generation and purchasing data. Generation and energy purchasing data collected under the program come from wind generation projects in California and with a rated nameplate capacity of at least 1 megawatt (MW).

Wind generation comprises a significant share of California's overall electricity generation. During 2014, California wind energy accounted for roughly 7 percent of the total in-state electrical energy generation and 29 percent of in-state renewable electricity generation. Wind generation also contributed to meeting energy standards and goals, such as the Renewables Portfolio Standard.

Statewide generating capacity during 2014 was just under 5,900 MW, spread among 130 generation projects. These projects generated about 13,000 gigawatt-hours (GWh) of electrical energy. Purchasers of wind energy reported buying almost 12,700 GWh of energy in 2014. This amount is 3 percent less than operators reported generating and may be due to uncertainties about specific sources and reporting errors. Purchases were highest in the second quarter and lowest in the fourth quarter, which parallel the reported statewide generation. Most energy was purchased by investor-owned utilities.

Two-thirds of the wind projects are classified as large, that is, 10 MW or larger in capacity. At 265, MW the Ocotillo Express project in San Diego County is the largest in terms of capacity as well as the most productive, having generated more than 500 GWh of electrical energy in 2014. Statewide, production was highest in the second quarter of 2014 and lowest in the fourth, with the large projects generating the highest production in June and the least in January.

The State has six designated wind resource areas that are specific zones containing many installed wind generation projects. The six areas are spread across the state from the Solano Resource Area in the north to the East San Diego County Resource Area in the south. The largest wind resource area is Tehachapi in Kern County, which is also the county with most wind generating capacity. With more than 4,000 turbines and more than 3,000 MW of capacity, the Tehachapi wind resource area produced more than half of the net energy for the year.

In addition to the wind resource areas, other, newer projects exist outside the wind resource areas, including a large project in Shasta County. A newer trend in

development is placing single or pairs of turbines at industrial or commercial facilities to offset energy consumed at the facility. Budweiser's two wind turbines at its Fairfield brewery in Solano County are an example.

California turbines span an age range of more than three decades and vary from early, mechanical machines of tens of kilowatts in capacity to modern, electronic machines of more than 3 MW. While many early turbines were installed on lattice towers, newer ones are installed on tubular towers. The composition of the turbine fleet has been dynamic as operators repower, retire older turbines, and start new projects. During 2014, six new projects totaling 104 MW started selling energy, while two totaling 27 MW were decommissioned. Also, ownership and operators of wind generation projects change frequently, contributing to the dynamism of the wind industry.

Besides capacity and generation, the capacity factor of a project indicates the production of the project during a specific period. *Capacity factor* (CF) is a widely used measure of generator output with respect to potential output. A generator that produced 25 percent of the energy that it could have if it had run at full power all year would have a CF of 0.25, or 25 percent. The larger the factor, the more electricity generated. Larger projects typically have higher capacity factors than smaller ones, and the summer months bring the higher capacity factors at most projects, while winter months are lower. For the large projects as a group, capacity factors by month ranged from 0.45 to 0.12. By wind resource area, Solano had the highest factor in July at 0.54. The timing of Solano's highest capacity factor when compared to other areas brings it closer to the time of peak electricity sales.

Staff examined this diversity by conducting an analysis using correlation coefficients between the capacity factors for the state's large wind resource areas (WRAs). Close correlation means that two or more areas share close generation timing, such as seasons. Results showed that the Altamont and Pacheco wind resource areas are most strongly correlated, and the weakest correlation was between Solano and Tehachapi. Results confirmed the hypothesis that closer WRAs would be more strongly correlated.

Although California's national and global stature has diminished somewhat in terms of the number of projects and capacities, it is still a leader in those attributes. In the United States, California ranked third in terms of capacity, behind Texas and Iowa. California wind generation comprised 9 percent of the nation's wind capacity and 7 percent of its wind generation. Globally, California capacity was 2 percent of worldwide wind generation by both capacity and energy.

As global use of wind generation increases, global manufacture of wind turbines and components grows as well. The leading countries of origin for California turbines are Denmark, followed by the United States, Germany, and Japan.

CHAPTER 1:

Introduction

California is one of the top three states in developed wind power capacity and hosts a wide variety of wind turbine types and sizes. Vistas of wind farms from major highways, as in **Figure 1**, are seen by thousands of residents and tourists every day.

Figure 1: View of Wind Farm by Interstate 10 Near Palm Springs



Source: Carol Cooper, whichwaynow101.wordpress.com.

Wind power continues to develop in the state in re-powering and new projects. In addition to established places like Tehachapi, projects are built in new locations like Shasta County.

The status of wind energy generation and purchases is of potential interest to a wide variety of parties. Policy makers, government agencies, grid operators, utilities, electric service providers, project developers, investors, and researchers may have an interest in the status and flow of wind energy in the state. Pursuit of renewable energy and clean-air goals leads to support of wind power. Utilities, municipalities, and consumers support growth through their purchase of wind and other renewable energy. Private companies invest in new generation projects and repowering existing projects.

Wind energy made up 30 percent of the total renewable energy generated in the state in 2014. For investor-owned utilities (IOUs) only, wind energy made up 36 percent of the energy meeting the Renewables Portfolio Standard (RPS) in 2014 (California Public Utilities Commission [CPUC], 2015a). An indication of the relative importance of wind energy for the RPS is found in the claiming of credits for energy by entities subject to the RPS. This claiming is referred to as the “retiring” of credits. In 2014, of the renewable energy credits retired for in-state energy, wind energy made up 24 percent of the total.¹

In addition to wind energy producers and purchasers, California hosts 15 manufacturing facilities making turbine components (AWEA, 2015). These are spread over the northern and southern parts of the state, making everything from hydraulics to composite coatings to power converters. They contribute to the state’s manufacturing economy and are part of the growing green economy of the state and the nation. Within the state the wind industry is estimated to have supported between 2,000 and 3,000 direct and indirect jobs in 2013 (AWEA-DS, 2015). Another economic benefit is lease payments to landowners at project sites in California that are estimated at more than \$10 million per year (AWEA, 2015).

This report describes and analyzes 2014 California energy data and places them in a larger national and global context. Facts provided are generally as of the fourth quarter of 2014, unless noted as for other periods. References to data as of the fourth quarter should be interpreted as end-of-year data, unless noted otherwise.

Data Collection and Scope

Two types of parties report data: wind generation operators and wind energy purchasers. Generation owners do not report data, but some information about them is reported by operators. After years of little or no collection, the Wind Performance Reporting System (WPRS) was revitalized in 2014 and contains a full set of data for that year.²

Effective January 1, 2014, the California Energy Commission began a new process for collecting energy data in the WPRS. Older data collection forms were revised, and staff undertook the task of identifying and contacting all wind plant operators and purchasers of in-state wind energy. The new forms combined reporting for wind plants from two regulations that covered wind energy and all power plants. In this way it streamlined reporting for wind operators and purchasers.

1 Angela Gould and Brian McCollough, California Energy Commission, Renewable Energy Division, in discussion with the author, December 21, 2015.

2 The need to collect wind energy information was codified in the California Code of Regulations Title 20 Sections 1381-1389 using the name “Wind Performance Reporting System” Title 20 California Code of Regulations Section 1304 also calls for reporting wind energy information as part of power plant reporting.

Data presented in this report draw primarily upon that reported in the WPRS. Some data and information from other sources are included to place the state wind information in context. Most reported data are for generation plants, with less data required of energy purchasers.

During 2014, reporting parties were learning to use the new forms and sometimes reported inconsistent or incomplete data. The wind energy community in California consists of many parties, and educating them in the required reporting involved many contacts by staff. Data covering 2014 was submitted as spreadsheets and PDF files, and then staff compiled it using an in-house database under development. When data reached the Energy Commission, staff reviewed them for completeness and reasonableness. Reporters were asked to correct omissions or errors. Reports were filed by quarter. Slight variations of some data entered by reporters are expected to decrease as reporters become familiar with the methods.

After extensive follow-up, staff is confident that the data obtained are a good representation of the state of wind energy in 2014 in California. With the transition to online reporting, automated data entry checks will be built into the software to improve consistency and data quality.

Staff did not visit operators or purchasers to verify reports, nor check metered or contractual information. The reporter is subject to the penalty of perjury under California law if reported data are not true, accurate, complete, and in compliance with regulations.

Energy data are reported in kilowatt-hours (kWh), as required by regulation. The precision of reported energy data is typically five to six significant figures. (Significant figures are here distinguished from places after a decimal to maintain proper precision.) Reported capacity precision varies and is usually three to four figures. Energy values are presented in this report as gigawatt-hours (GWh) in most cases.

The accuracy of the data can be affected by the reporter's attention to detail in internal recordkeeping, compliance with the regulation and reporting forms, and consistency of the reports from quarter to quarter. For these reasons, accuracy of the data is quite good, but not perfect. Staff experience suggests that the accuracies for the year are within 2 percent in the capacity and number of projects and within 4 percent in the number of turbines. An exact count of turbines would require extensive field verification and would add little to the picture already obtained of the state's wind energy supply.

The WPRS covers the entire state, in contrast to the California Independent System Operator (California ISO), the previous source of wind capacity data that covers about 80 percent of the state. The California ISO excludes balancing areas along the northern border, the southeast, and in several other areas around the state. For example, the areas of PacifiCorp, the Imperial Irrigation District, and the Balancing Area of Northern

California are excluded. The California ISO also collects shorter-term energy data than the WPRS does.

The data set includes generation and purchases from in-state wind energy plants. In addition to native wind power, California also imports wind energy from other states, but that energy is not examined here.

A “project” refers to a set of one or more wind turbine generators installed in California, the electricity from which is sold to another party. A project is operated by one operator. In this report, wind “plant” and “farm” are used as synonyms of wind “project.”

Both the generation and purchase data presented cover energy from plants of 1 megawatt (MW) and larger nameplate capacity.³ Projects of this size primarily produce energy for sale to utilities, energy service providers, or commercial customers. Projects under this size typically serve residential and small business users.

Data are reported by calendar quarter; for example, the first quarter includes the months of January through March. The data don’t include periods shorter than one month and are therefore on a longer basis than sources with hourly data. Previous reports by others have analyzed variations in wind generation on shorter time scales. This report examines the variations at monthly and quarterly time frames, which provide a longer-term perspective on system operation and characteristics, tending to smooth out short-term variations.

Report Organization

This report presents data and analyses of wind generation and energy purchases and provides context for the analysis and values presented. Chapters 1 through 4 discuss generation in capacity and energy throughout the state, by region, and in breakdowns by type of generator. Chapter 5 explains the capacity factors statewide and regionally. Chapter 6 analyzes correlations of capacity factors, both using all large projects, as well as using the wind resource areas. Chapter 7 presents data and analysis on purchases of wind energy. In Chapter 8, the context for California generation is presented in statewide energy, national and global wind generation, and the wind resources of the state. Chapter 9 summarizes the analyses.

³ *Nameplate capacity* is the full-power rated electric capacity of a wind turbine (or group of turbines). This capacity is the maximum power output level as designed.

CHAPTER 2:

Statewide Capacity, Energy Production, and Activities

In the WPRS, wind generation plants are classified by size, either large (at least 10 MW) or small (under 10 MW). The capacities are manufacturer's nameplate capacities. State regulations require that large plants report energy generation for each month, and small plants report generation for each quarter; plants under 1 MW do not report. In this scheme, no plants are referred to as "medium." Staff had to make energy estimates in a few cases where data were reported in the wrong time frame.

Plants sometimes fluctuate in reported capacity near the threshold of 10 MW, crossing above or below this level from one period to the next. Divisions between the two subsets of the large and small plants are not absolute in all cases. These minor differences, however, do not change the overall status of wind production in the state.

Data are reported quarterly, and fourth quarter reports are end-of-year data. At the end of 2014, there were about 130 wind plants available to generate. Of the total number of plants, two-thirds (86 plants) were large, and one-third (44 plants) were small. All projects combined contained about 11,500 turbines. Although the fleet changes from quarter to quarter, this report provides a thorough snapshot of the status at the end of 2014, the first full year of data collection.

Generators report capacity data both in total and by turbine groups. Although the total capacity equals the sum of group capacities in most cases, some organizations reported total values that did not exactly equal the sums of groups. The effect of this difference was small.

The status of the turbine fleet is dynamic. The number of operating generation plants changes from quarter to quarter and month to month as plants change owners, operators, and sales contracts. Projects, turbines, and capacity fluctuate as projects are built, decommissioned, expand, or repower. In some cases, plants enter litigation and do not report data to the Energy Commission during a period of months or years. In a few cases of non-reporting, staff can estimate generation data using information from energy purchasers. A project in litigation may have a legal obligation to report data. In practice, however, this reporting may not be obtainable without stringent regulatory enforcement. So far, litigation has not warranted enforcement action.

In older projects, operators sometimes keep a few malfunctioning turbines out of service while the majority continue to produce. Older projects can have many smaller units of old equipment, and the net gain from servicing a nonfunctioning turbine may be low. In addition, operators of older projects with many small turbines may not know

the exact count of available turbines, either for their project or of one model. This is in contrast to newer projects and turbines, where condition monitoring and diagnostic systems can lead to early fault detection and pre-emptive maintenance.

Capacity

California's wind fleet comprises nearly 5,900 MW of capacity from in-state plants as of the fourth quarter. The largest generating project is 265 MW.⁴ The median capacity of all plants is 22 MW, and the mean capacity is 45 MW. Large plants make up 97 percent of all capacity, and small plants are 3 percent.

The WPRS provides data on available wind capacity in the state. Previously, data on capacity from the California ISO were used for the Energy Commission's Renewable Energy Tracking Progress Report, available on the Energy Commission's website.⁵ WPRS data show that wind capacity in California was about 1,300 MW lower in 2014 than California ISO January 2015 estimates. California ISO wind data reflected the uppermost planned capacity for wind projects, which was used for transmission planning. The WPRS data reflect plants installed and available to generate.

Energy Production

In-state plants produced 13,074 GWh net energy during the year. Net generation is gross generation minus station use energy. Station use energy is that used to operate the plant, including amounts consumed for plant lighting, auxiliary facilities, and other needs. The median net energy produced among the plants was 34 GWh, and the mean of all plants was 101 GWh, pointing to many plants toward the lower end of the energy production range.

The most productive projects produced more than 500 GWh each during the year. Fourteen of the 130 plants each produced more than 300 GWh net. **Figure 2** displays net energy production during 2014 by quarter for all plants. Quarterly production was highest in the second quarter of the year (April through June) and lowest in the fourth quarter (October through December).

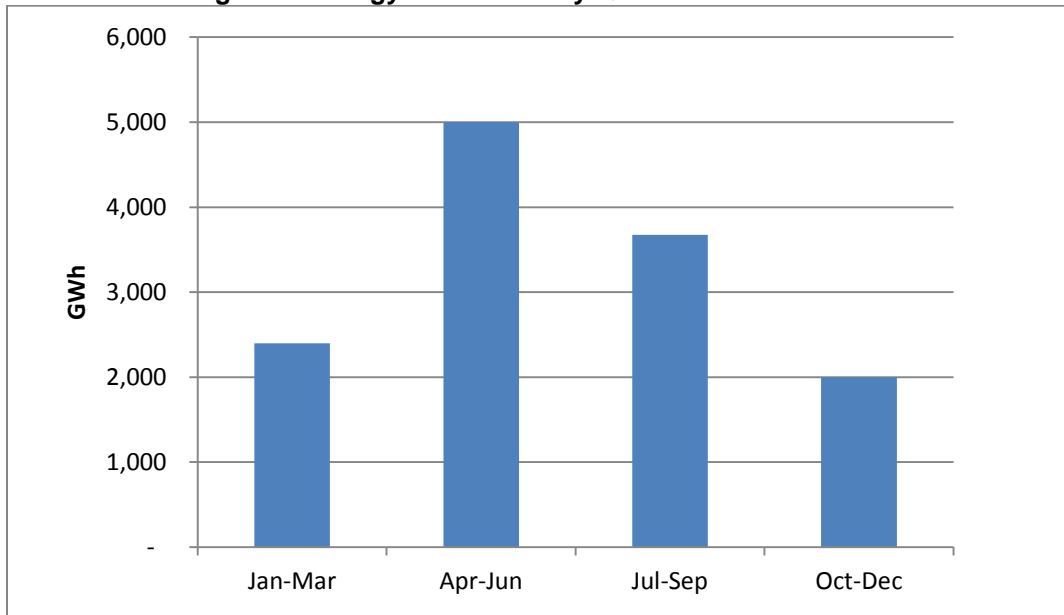
Patterns of energy production within the year are of interest for the value of the energy produced. Demand for electricity is higher in the summer months in much of California, when air-conditioning loads are higher. Energy produced during the summer typically has a higher market value in the state than energy produced in winter.

A subset of only the small plants shows a parallel annual pattern. Highest production occurred in the second quarter and lowest occurred in the fourth quarter. **Figure 3** illustrates this trend.

⁴ The American Wind Energy Association combines several projects into one, resulting in a higher capacity. The maximum project size is based on reports to the California Energy Commission.

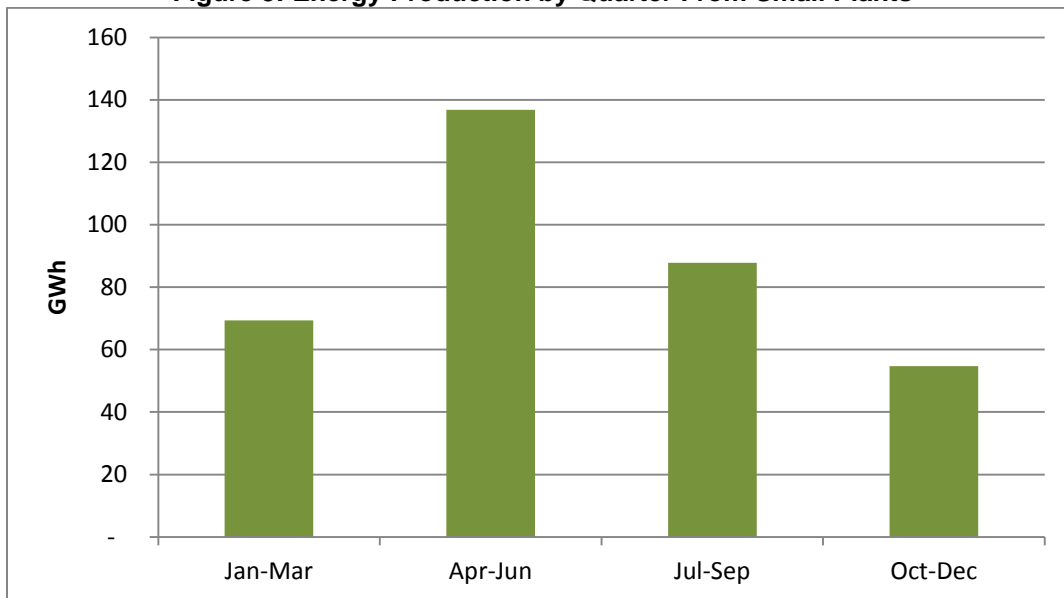
⁵ See: http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf.

Figure 2: Energy Production by Quarter From All Plants



Source: Energy Commission, Supply Analysis Office.

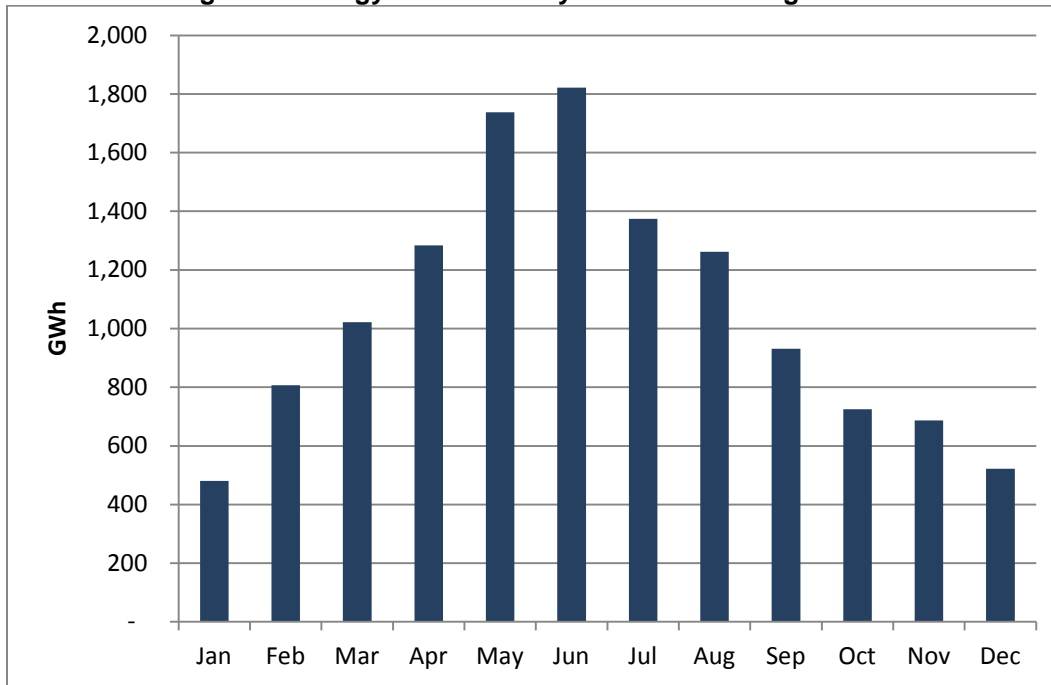
Figure 3: Energy Production by Quarter From Small Plants



Source: Energy Commission, Supply Analysis Office.

Monthly production by large plants brings out the seasonal pattern more specifically. The highest generation occurred in June and lowest in January. May was the second highest month, and July the third highest, as **Figure 4** depicts. Because large plants represent the majority of all plants, **Figure 4** is a close approximation of the monthly production from all plants.

Figure 4: Energy Production by Month From Large Plants



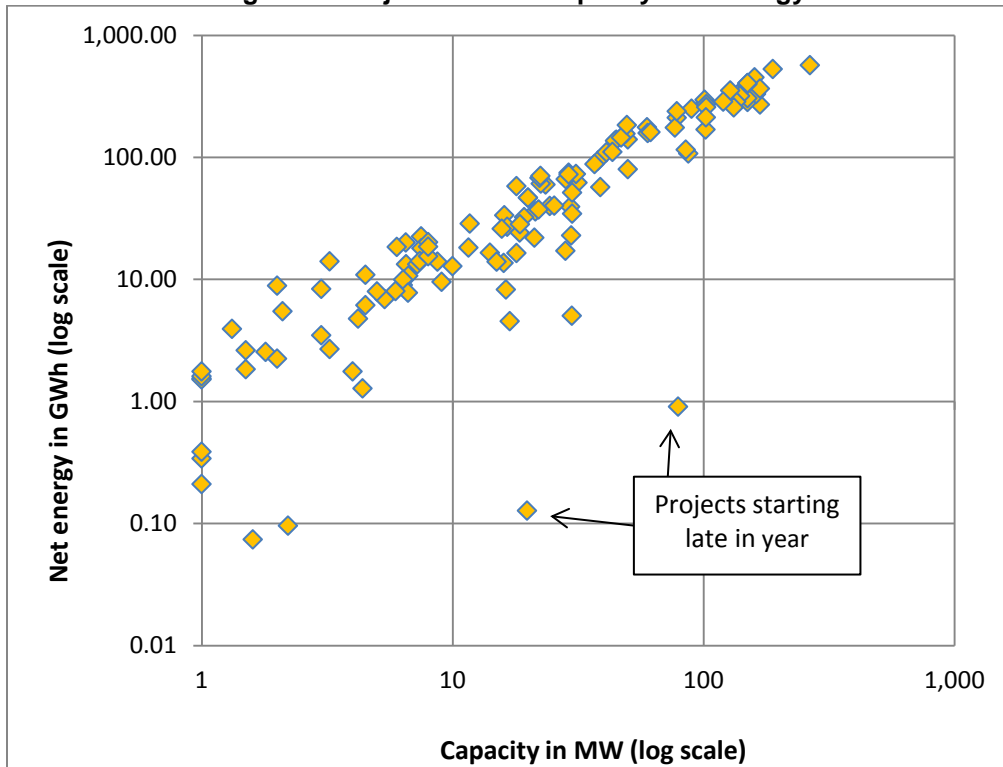
Source: Energy Commission, Supply Analysis Office.

Comparing project net energy generated to project capacity shows the distribution of projects in terms of capacity and energy produced. **Figure 5** displays the projects on log-log scales⁶ to illustrate the orders of magnitude and groupings of the projects. A scattering of projects exists in the range of fewer than 10 MW and under 10 GWh for the year. Many occupied the space of a few tens of MW and tens of GWh. Another large group reached the zone of the low hundreds of MW and hundreds of GWh for the year. Two projects that came on-line near the end of 2014 are apparent on the graph at points of moderate capacity and low energy production. The grouping of projects at 1 MW reflects the lower threshold of required data reporting.

The seasonal pattern of California wind production can also be compared to patterns worldwide. Wind speeds vary from year to year with changes in weather around the globe, and speeds over California varied by quarter. The first quarter saw below-average speeds over most of the state. In the second quarter, speeds were below average over land near the coast and average to slightly above average farther inland. The third quarter continued this pattern but with smaller portions of the state experiencing above-average speeds. The final quarter had above-average speeds in the northern part of the state and below average in the southern part (AWS Truepower).

⁶ *Log-log scales* refers to a graph where the two scales are in logarithmic proportions, rather than linear proportions.

Figure 5: Project Sizes in Capacity and Energy



Source: Energy Commission, Supply Analysis Office.

Besides the energy and capacity provided, wind energy can have additional value. One important benefit to California is water savings, and this is important for long-term water conservation in light of the recent drought years. Wind generators use very little water, as they do not use a heat-transfer fluid to spin a turbine, as conventional generators do.

Time Comparison to Retail Electric Sales

Variations in monthly wind generation during the year can be compared to average monthly electricity retail sales. This indicates how closely the peak in wind generation corresponds to the peak in electricity consumption. Sales data on a monthly basis are available for the period of 2008 - 14 and are based on utility bills to customers.⁷ Electricity monthly sales data may be used as a proxy for monthly consumption, although the two are not the same, because 1) there are offsets between the time of consumption and the time of sales, 2) sales data do not include line losses, and 3) electricity consumption also includes nonsales electricity used onsite, which is known as self-generation (behind the meter) data. Self-generation data are not available at the monthly level, so monthly sales data are the best available for this purpose. The addition of self-generation data would not be significant for understanding monthly variations in electricity consumption. Average electricity sales show a yearly peak in

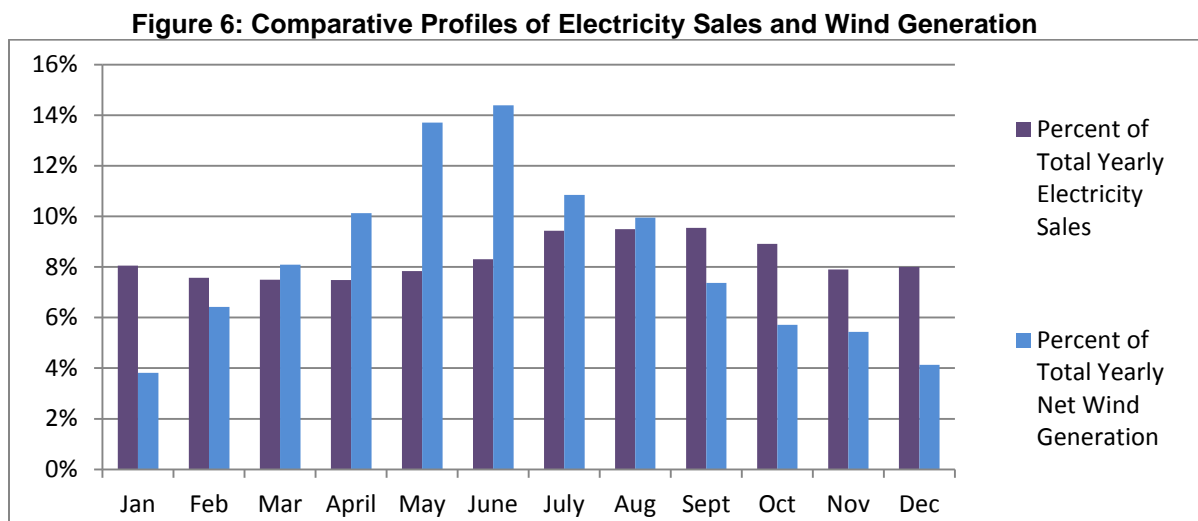
⁷ Steven Mac, California Energy Commission Demand Analysis Office, in discussion with author, September 2016.

September, with high sales also in August and July. Average electricity sales are lowest in April.

The sales trend can be compared to monthly wind generation in 2014 for large generators (the majority of generation). Monthly wind generation peaked in June, was slightly lower in May and lower yet in July. The lowest month of the year was January.

Statewide, wind generation peaked roughly three months earlier in the year than average electricity sales. Wind also reached the minimum for the year about three months earlier than average monthly sales.

These patterns are shown in **Figure 6**, which compares average electricity sales to 2014 net generation from large generators. The electricity sales peak on average in the late summer; the profile is fairly even throughout the average year. The large wind generator output peaked in the early summer with a more pronounced peak.



Source: Energy Commission, Supply and Demand Analysis Offices.

This generation pattern was not equally true at each wind resource area (WRA) of the state. Geographic differences in peak generation by quarter are discussed in Chapter 5.

Typical California Turbines

California hosts a wide variety of wind turbines within the state borders. Turbines started operating in the state in the early 1980s and continue to be installed today. Over three decades, turbine technology has advanced greatly. Early turbines resembled early farm tractors, while current state-of-the-art turbines are on the technology level of an airplane. In some respects, modern performance requirements exceed those of aircraft; the number of mechanical fatigue cycles and the cost constraints are greater for large wind turbines than large aircraft.

While early turbines used mostly mechanical control, current turbines include electronics and computer controllers. Current turbines are self-monitoring, provide

condition status to operators over a distance, and contain software to regulate power output. To illustrate typical turbines in use in California, two examples of installed machines are described below.

The first is an older, smaller turbine made in the San Francisco Bay Area by Kenetech: the model KCS 56-100. This machine has a capacity of 100 kW, a rotor diameter of 17 meters (m), and a weight of 7 metric tons (tonnes) for the rotor and nacelle (wind turbine models, 2015). (The nacelle is the workroom behind the rotor housing the drive shaft, gearbox, and generator.) It has a cut-in wind speed of 5 meters per second (m/s) and a cut-out⁸ speed of 22 m/s. It rotates at 72 revolutions per minute (rpm). Many were installed on steel lattice towers that can provide perching places for birds. A photo of these turbines installed is shown in **Figure 7**.

A larger, modern turbine is the Vestas V90 3.0. Vestas was founded in Denmark but has now established facilities in many countries, with a strong presence in the United States. This turbine has a capacity of 3.0 MW, a rotor diameter of 90 m, and a weight for the rotor and nacelle of 111 tonnes. It cuts in at a wind speed of 4 m/s and cuts out at 25 m/s. The nominal rotational speed is 16 rpm. Most are installed on tapered steel towers, which do not provide bird perches. The lack of perching opportunities reduces the environmental impact of a wind project. This turbine is shown in **Figure 8**.

Figure 7: Kenetech 100 kW Turbines



Source: See <http://en.wind-turbine-models.com/>.

⁸ The *cut-in speed* is the wind speed at which the turbine begins to generate electricity. The *cut-out speed* is the wind speed at which the turbine stops generating electricity. These speeds are designed into the turbine controller and are specific to the particular model.

Figure 8: Vestas 3 MW Turbine



Source: Wikipedia.

Ongoing Activities Affecting Generation

A project to connect roughly 3,800 MW of new wind capacity is in progress in Southern California (AWEA-DS, 2015). The Tehachapi Renewable Transmission Project is under construction by Southern California Edison Company (SCE) in Kern, Los Angeles, and San Bernardino Counties. This project includes new and upgraded transmission infrastructure along roughly 170 miles of new and existing right-of-way from the Tehachapi WRA in southern Kern County south through Los Angeles County and east to Ontario (CPUC, 2015b).

Recognizing that wind plants can affect wildlife, especially where plants are not well designed and operated, the Energy Commission funded research on impacts to bats and birds near wind turbines starting in about 2000. This research focused on the Altamont WRA and led to recommendations on turbine siting and on management of bird prey species, especially during repowering. Since 2013, the Energy Commission has funded studies of golden eagles, particularly in the Mojave and Sonoran Deserts.⁹ These ongoing investigations are developing methods to estimate golden eagle density and abundance, and the relationship between prey availability and nesting success. Upcoming studies extending beyond 2014 will conduct comprehensive reviews of bat and avian species and compare impact predictions to monitoring data.

⁹ David Stoms, California Energy Commission, Energy Research and Development Division, in discussion with the author, October, 2005.

Additional activities relating to environmental impacts are detailed in an environmental performance report prepared by the Energy Commission (Bartridge, 2016).¹⁰ They include a 2005 recommendation that protocols be developed for studying avian mortality to address site-specific impacts at individual wind resource areas. In 2007, the Energy Commission adopted voluntary guidelines for reducing impacts to birds and bats from wind energy development, and in March 2012 the U.S. Fish and Wildlife Service issued guidelines for land-based wind energy. Both guidelines inform practices to decrease impacts in wind facility siting. The state has also worked with the U.S. Department of Defense to limit potential conflicts with military installations and training that could arise from renewable energy and transmission projects.

The Renewable Energy Transmission Initiative (RETI) is a planning process in which first phase ended in 2010, and the second phase began in October 2015.¹¹ RETI 2.0 is a proactive, statewide, non-regulatory forum to identify the constraints and opportunities for new transmission to access and integrate new renewable resources and help meet the state's greenhouse gas and renewable energy goals. In addition to energy, environmental, and agricultural stakeholders, RETI 2.0 seeks voluntary participation from tribal and local governments, public power entities, other western states, and regional energy planning bodies to help look for solutions that serve multiple interests.

10 Kevin Barker, California Energy Commission, Commissioners Office, email message to author, December 14, 2016.

11 Al Alvarado, California Energy Commission, Siting, Transmission and Environmental Protection Division, in discussion with the author, December 2015.

CHAPTER 3:

Generation by Wind Resource Area

California contains six recognized WRAs, where development is established. In order from north to south, they are:

- Solano.
- Altamont.
- Pacheco.
- Tehachapi.
- San Geronio.
- East San Diego County.

The established WRA locations are shown in **Figure 9**. Early studies of wind power potential in California identified several WRAs as having high wind resources and being close to grid-access points. As newer resources were developed, such as at East San Diego County, additional WRAs were added to the list. The WRAs did not represent all the available wind resources in the state, and they did not represent limits for future expansions of the electric grid.

The size of each WRA depicted on the map indicates the distance between projects within the WRA, and individual projects may be far apart, as in East San Diego County. Within a project, actual equipment takes up only a fraction of the project area due to the spacing between towers. The footprint of a wind generation project includes the tower foundations, access roads, electrical equipment, and the workshop and office. The space between towers can be part of multiple land use, in areas where livestock grazing or other beneficial activities are conducted between tower foundations.

Figure 9: Locations of Established Wind Resource Areas



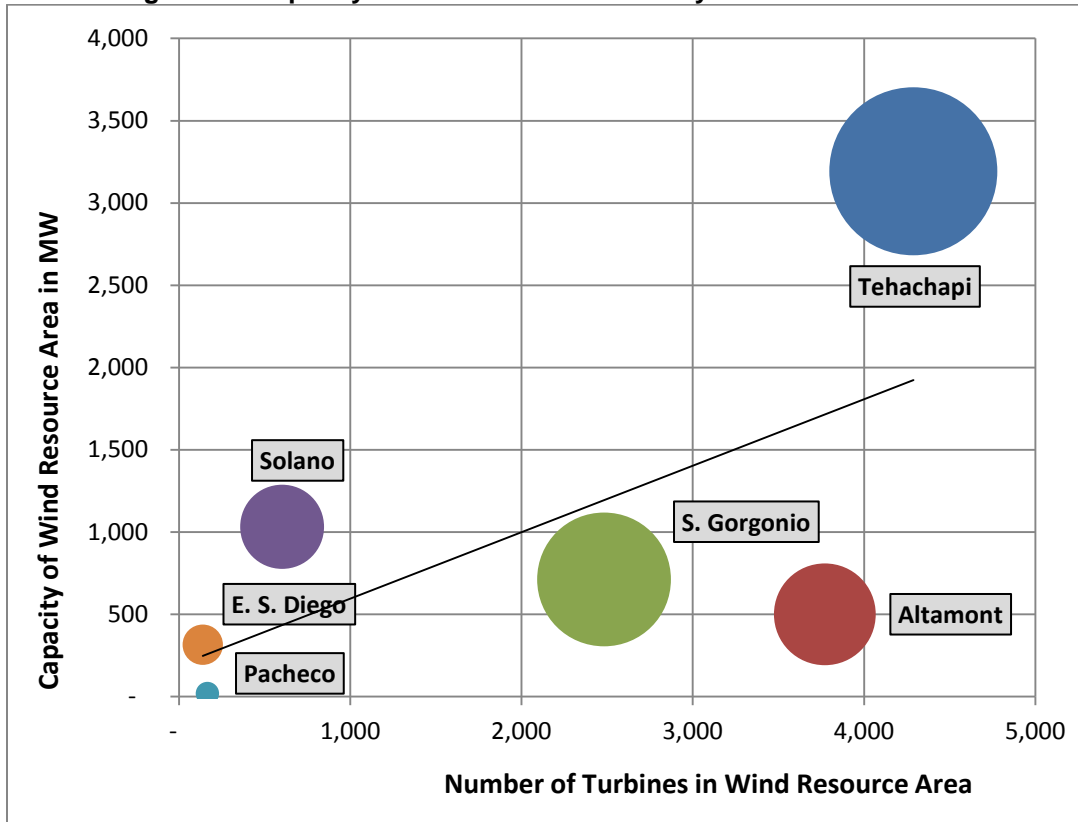
Source: Energy Commission, STEP Special Projects Office.

Differences in Wind Resource Areas

The California WRAs differ markedly in capacity, number of turbines, and number of projects. Tehachapi is the largest WRA in both MW and number of turbines. Solano, San Geronio, and Altamont are smaller and occupy three positions in the chart of capacity versus numbers of turbines in **Figure 10**. Numbers of projects in each WRA are indicated by the size of the data circles in **Figure 10**. East San Diego County and Pacheco

WRAs are smaller in capacity and number of turbines. A linear trend line¹² is superimposed as a guide to the proportion between capacity and number of turbines for each WRA. WRAs falling above the trend line have a higher ratio of capacity to number of turbines and have, on average, larger turbines compared to those WRAs below the line. The positions above the trend line of Solano and Tehachapi, reflect that they have more modern turbines with higher average capacities. In Pacheco, San Gorgonio, and Altamont, the turbines tend to be older, lower-capacity turbines.

Figure 10: Capacity vs. Number of Turbines by Wind Resource Area



Source: Energy Commission, Supply Analysis Office.

These numbers support the opportunity for re-powering at Pacheco, San Gorgonio, and Altamont, which could take advantage of more recent, higher capacity technology. Re-powering is, however, a complex decision by the owner, involving project economics, grid connection limitations, and contractual considerations. Although areas like San Gorgonio and Altamont offer opportunities for higher productivity after re-powering, an owner may choose not to re-power under current conditions. These conditions may change as project economics change, the grid evolves, or contracts reach their terms.

¹² The trend line used here is linear, rather than polynomial, exponential, or of another type. The linear is the simplest type of trend line.

In addition to the six established WRAs, projects have also been built at other California locations, a few close to existing WRAs and some in entirely new areas. Technology advancements allow winds over more parts of the state to be used. There are also a few small projects to serve large commercial facilities that can consume the energy generated on-site.

One large generator in a newer part of the state is the Hatchet Ridge project in Shasta County. This 101 MW project is west of the town of Burney; **Figure 11** depicts the project looking northwest with Mount Shasta on the horizon.

Figure 11: Hatchet Ridge Wind Project



Source: Sergio Gonsales, Pattern Energy.

WRAs can be compared by parameters, including net energy produced during the year, capacity, number of projects, and number of turbines. In addition, ratios of the capacity per plant and capacity per turbine are also useful in understanding how the WRAs differ. These ratios may be interpreted as mean values for each area. The values are listed in **Table 1**. Energy values apply to the full year 2014, and other values are as of the end of the year. “Other Resource Area” refers to projects not located in one of the WRAs. “Outside Existing Area” indicates projects near, but not within, a WRA.

The East San Diego County WRA had the highest capacity per plant, with the Solano area next highest. Both these WRAs have a large fraction of higher-capacity turbines. The East San Diego County is dominated by the Ocotillo Express project with its large turbines.

Energy percentages of the statewide total for each area are shown in **Figure 12**.

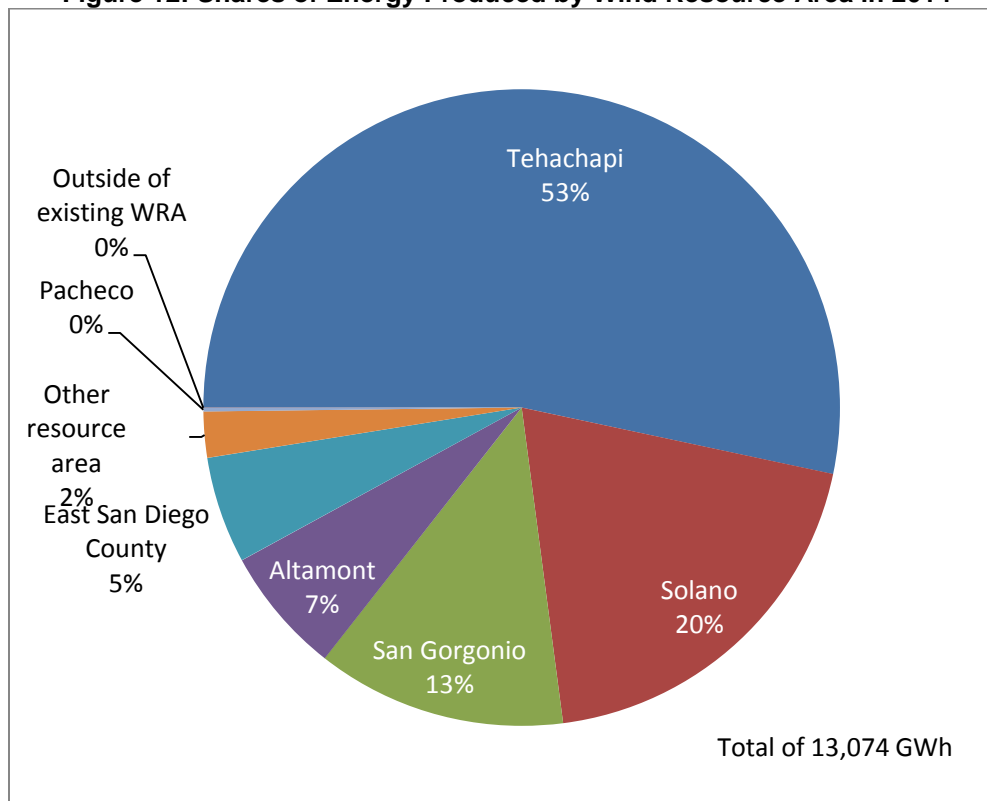
Tehachapi produced more than two times more energy than the next most productive WRA, which was Solano.

Table 1: Comparison of Wind Resource Area Parameters

Wind Resource Area	Capacity (MW)	Energy (GWh)	Number of Projects	Number of Turbines	Average Capacity per Project (MW)	Average Capacity per Turbine (MW)
Tehachapi	3,193	6,976	52	4,288	61	0.7
Solano	1,032	2,559	13	602	79	1.7
San Geronio	712	1,657	33	2,482	22	0.3
Altamont	500	843	19	3,771	26	0.1
East San Diego County	316	708	3	138	105	2.3
Other Resource Area	111	306	7	52	16	2.1
Pacheco	19	24	1	165	19	0.1
Outside of Existing WRA	3	2	2	2	1	1.2
All Areas	5,887	13,074	130	11,500	45	0.5

Source: Energy Commission, Supply Analysis Office.

Figure 12: Shares of Energy Produced by Wind Resource Area in 2014



Source: Energy Commission, Supply Analysis Office.

CHAPTER 4:

Categorical Data of Generators

WPRS data include turbine numbers, capacities and energy, as well as other data on rotor swept area,¹³ turbine manufacturer, turbine model, and other categories. The portfolio of turbines changes with every reporting period. Values presented below are as of the fourth quarter of 2014.

Turbine Capacity

Capacity data are reported by turbine group in each generating project. A group includes a set of turbines that are of the same make, model, and capacity. Capacities of single turbines spanned a wide range from 40 kW (0.040 MW) to 3.3 MW. Many turbines are reported at sizes of 100 kW and below, with decreasing numbers at higher capacities. The most common capacity of 100 kW was represented by almost 3,000 turbines, followed by the size of 65 kW, represented by almost 2,000 turbines.

These sizes represent an earlier era of turbine technology. In new large projects, turbines in the range of 2 MW or more are commonly being installed. Small industrial site owners with only one or two turbines are also selecting turbines of at least 1 MW. These take advantage of the efficiencies offered by modern, larger machines. An example is the Teichert Vernalis project in San Joaquin County, where Foundation Windpower, LLC operates a 1.5 MW turbine.

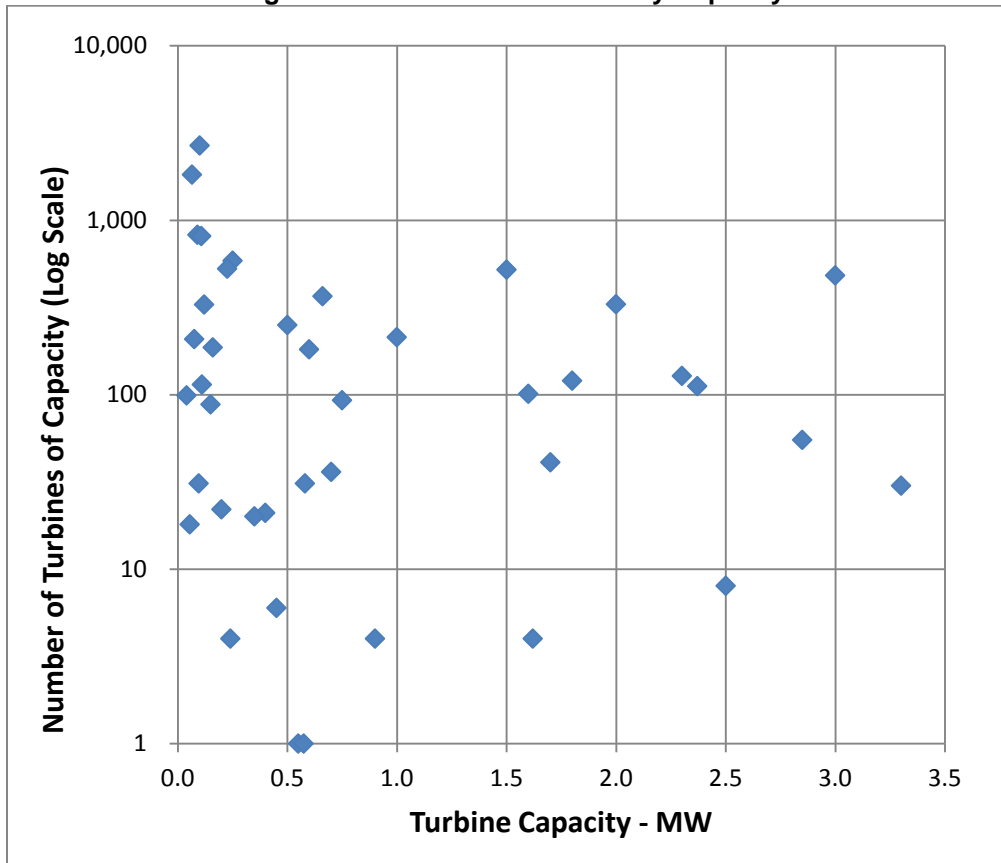
Figure 13 depicts the number of turbines statewide of each capacity on a semilog graph. It illustrates that in the size range of more than 1 MW, there are relatively few turbines installed. In the under 1 MW range, many turbines are installed.

The average turbine size in the United States is 1.9 MW as of 2014 (AWEA-DS, 2015). The average U.S. turbine is considerably larger than the average one in California (0.5 MW). Texas and other states experienced a surge in capacity in subsequent years compared to California and benefited from the presence of larger turbines in the market than when California started developing projects.

These sizes are also below current global market offerings; the largest turbines on the market are 8 MW (GWEC, 2015). Manufacturers continue to bring larger turbines to market to allow owners to produce energy at lower costs.

¹³ The *swept area* is the circular area that the blades sweep out as they rotate, measured in square meters.

Figure 13: Number of Turbines by Capacity



Source: Energy Commission, Supply Analysis Office.

Rated Speed

Wind turbines are designed to cut in (meaning to start generating) when the wind reaches a minimum speed. Power output increases as wind speed increases to a rated wind speed, at which point full power is produced. Above this rated wind speed, power output is constant until the maximum operating wind speed is reached. When the maximum operating speed is reached, the turbine shuts itself off to protect the mechanical and electrical systems. Typically, the rated speed is in the range of 12 m/s to 17 m/s ([WindPower program](#), 2015). For 2014, California turbine groups had a median rated speed of 14 m/s.

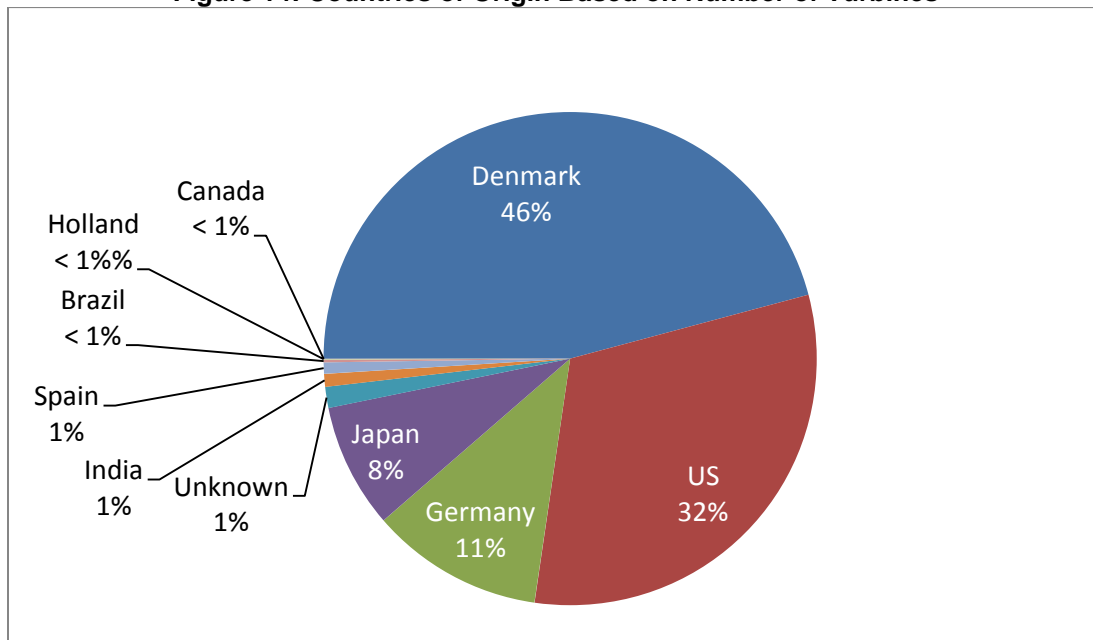
Rotor Size

Rotor size is reported by turbine groups in square meters (sq. m) of swept area per turbine. The areas ranged upward to more than 9,800 sq. m each in California. The largest turbines had a rotor diameter of 112 m. Eighty percent of turbines nationwide have a rotor diameter of 100 m or greater as of 2014 (AWEA, 2015). The size trend nationally is upward, as new turbine models are developed to capture lower winds at additional sites. Manufacturers are developing better technology to control the machine stresses induced by longer blades.

Origin of Turbines

The national origin of turbines, whether domestic or foreign, has been a subject of much discussion nationally in the last few years. The California turbine fleet was made in a variety of countries. Manufacturers of California's turbines over the years have been founded, merged, sold, and gone out of business. By numbers of turbines, California turbines were made by companies in Denmark, the United States, Germany, and Japan. Origins are shown in **Figure 14**. American manufacturers supplied 32 percent of the turbines in the California fleet.

Figure 14: Countries of Origin Based on Number of Turbines

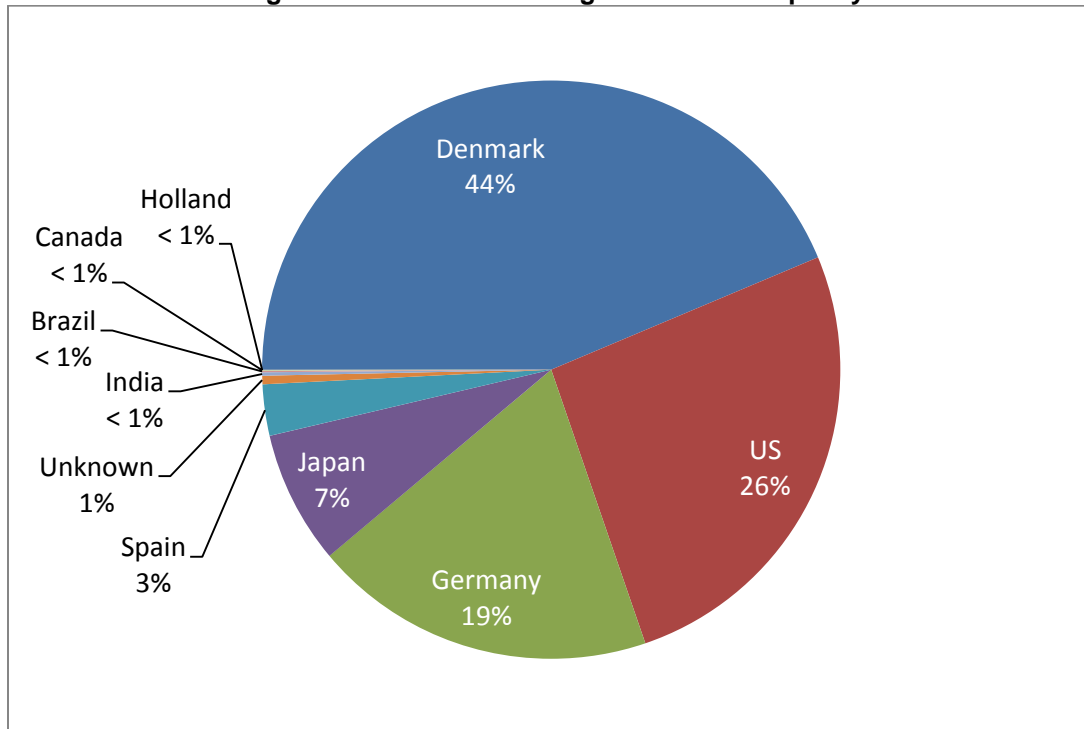


Source: Energy Commission, Supply Analysis Office.

When manufacturers of installed turbines are analyzed on a capacity basis, similar patterns emerge. Denmark is still the largest country of origin, as shown in **Figure 15**. The United States, Germany, Japan, and Spain assume the next leading places. The fact that many Kenetech turbines are low-capacity models is reflected in the decrease of the American percentage. This reflects the presence of many low-capacity, older turbines in the fleet. United States manufacturers supplied 26 percent of the capacity in the fleet.

Many older turbines are moving out of warranty, and manufacturers are diversifying into turbine maintenance services. There is an increasing emphasis on preventive maintenance as more sophisticated tools are becoming available to monitor and diagnose early indications of equipment problems.

Figure 15: Countries of Origin Based on Capacity



Source: Energy Commission, Supply Analysis Office.

In order of U.S. capacity, the leading turbine manufacturing companies are General Electric (GE) Energy (United States), Vestas (Denmark), Siemens (Germany), and Gamesa (Spain), including the predecessor manufacturers of these companies (AWEA-DS, 2015). Almost every brand of the 10 leading manufacturers or predecessors is represented in the current California fleet.

Manufacturing capability in the United States is strong for several turbine components, including nacelle assemblies, towers, and blades. However, equipment within nacelles is largely imported (WWPTO, 2015).

Globally, the leading suppliers of turbines for the year were Vestas (Danish), Siemens (German), GE (American), Goldwind (Chinese), and Enercon (German) (BTM Navigant, 2015).

Models in Use

Analysis of reported turbine models in California by number shows that the Kenetech KCS 56-100 is the most common model, with 2,600 in use. These early technology turbines were installed in the late 1980s, and they continue to produce energy that can be sold. The Vestas V-17 is the next most common, with more than 800. Other prevalent models include the Vestas V-15 (with more than 700) and the Bonus 250 (with almost 600).

On a capacity basis, the most important turbine models are the Vestas V 90, with 1,500 MW in use, the GE 1.5 (with almost 800 MW), the Siemens SWT 2.3 (with almost 600 MW), and the REpower 92 MM (with almost 500 MW).

Generation Operators

Wind generating plant data are reported by plant operators, who tend to be near generators and may operate many projects by agreement with plant owners. Almost 60 operating organizations were active as of 2014 fourth quarter, and they operated plants ranging from 2 MW to more than 1,300 MW in capacity.

The biggest operators in the state by capacity are Terra-Gen Operating Company, EDF Renewable Services, and Iberdrola Renewables. By number of turbines, the top operators are NextEra Energy Operating Services, Terra-Gen Operating Services, and EDF Renewable Services. The greatest in number of projects include Terra-Gen Operating Services, EDF Renewable Services, and NextEra Energy Operating Services.

Generation Owners

Owners are not required to report data. California wind generators are owned by a wide variety of parties, including many formed to own particular plants. Owners are located in a number of states and in Canada. As of the fourth quarter of 2014, there were more than 100 owning organizations in the state, and the organizations owned projects from 1 MW to more than 200 MW in capacity.

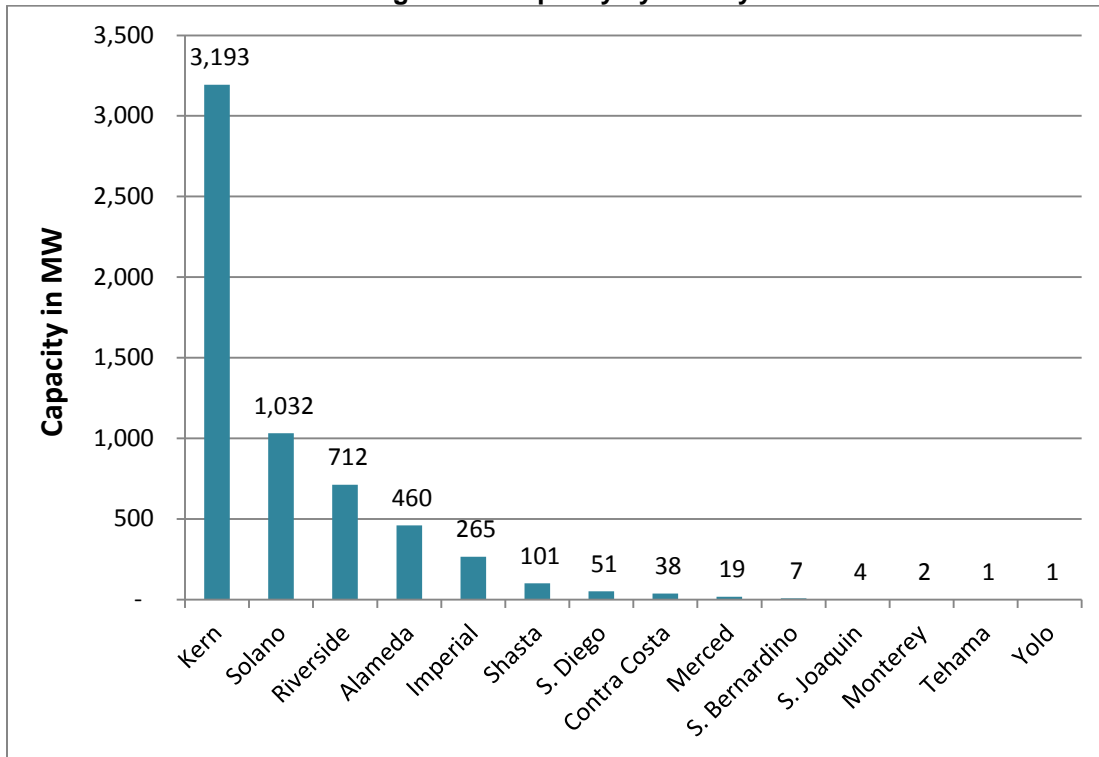
Top owners by capacity included Ocotillo Express LLC, Manzana Wind LLC, and Alta Wind V LLC. By number of turbines, top owners included Green Ridge Power LLC, Windpower Partners 1987 LP, and Forebay Wind LLC. In terms of number of projects, leading owners were Wind Stream Operations, AES Wind Generation, and Foundation HA Energy Generation LLC.

In-state owners that also hold major shares of total U.S. capacity include NextEra Energy, EDF Renewables, British Petroleum Wind, and AES. Nationally, wind capacity was owned primarily by independent power producers, with smaller shares by IOUs and publicly owned utilities (POUs) (WWPTO, 2015). Many operators and owners are limited liability corporations, including all of the top 10 owners by capacity. Many others are owned by limited partnerships. California IOUs do not own wind plants in-state, but LADWP and SMUD do.

County Location

Kern County has by far the greatest amount of installed capacity. This is followed by Solano, Riverside, and Alameda Counties, as shown in **Figure 16**. More than a dozen counties host wind plants of at least 1 MW. Several newer projects designed to serve on-site users are reflected in counties with very small amounts of capacity.

Figure 16: Capacity by County



Source: Energy Commission, Supply Analysis Office.

Counterparties

Operators report parties to whom projects sell energy, as well as contract names. They report selling energy to IOUs, commercial consumers, POUs, and energy service providers (ESP). By type of counterparty, most installed capacity was contracted to IOUs, with smaller fractions of capacity contracted to POUs and to ESPs and other parties. These data are distinct from those reported by energy purchasers.

Derived Quantities

Some quantities are not reported, but they can be derived from reported data. Specific power (or specific capacity) and specific energy are two examples. California projects report capacity and energy production by turbine group rather than by individual turbine. The values for the California fleet are based on reported, site-specific data and are not nominal or design values.

Specific Power

Specific power is a common measure of the power per unit of rotor area from a turbine or group of turbines.¹⁴ Turbine groups in California had a median specific power of 0.38 kW per square meter (kW/m²). Specific power generally varies from 0.20 kW/m² for

¹⁴ Specific power is not the same as “specified” power. The latter is electrical generation that is directly attributable to a known generation resource.

a smaller-diameter rotor to 0.50 kW/m² for a larger one (Patel, 2006). For existing, commercially available turbines in sizes of 0.6 MW to 4.5 MW, it ranges from 0.30 kW/m² to 0.50 kW/m² (Jackson, 2005).

Higher specific power values are generally more economic at sites with higher wind speeds, and lower specific powers are more suitable at lower-speed sites. There has been a trend toward lower-speed sites in recent years. As of 2014, specific power nationwide averaged 0.25 kW/m² (WWPTO, 2015).

Specific Energy

Specific yield or (specific energy) is a measure of the energy per unit of rotor area. Values typically range from 800 kWh/m² to 1,000 kWh/m² or more, as of 2000 (Hau, 2000). Generally, larger-diameter turbines installed at taller heights achieve a higher specific energy than smaller, shorter turbine installations. California groups of wind turbines average about 680 kWh/m² for all projects. This value may reflect the large number of smaller turbines in the state.

CHAPTER 5:

Capacity Factors

Actual energy production is often compared to the hypothetical output of a plant running at 100 percent of capacity full time. *Capacity factor* (CF) is a widely used measure of generator output with respect to potential output. A generator that produced 25 percent of the energy that it could have if it had run at full power all year would have a CF of 0.25, or 25 percent. Although the CF is most often stated on a yearly basis, it can also be calculated for a quarter or another period using a different number of hours.

A CF for a year represents a summation of the instantaneous output levels over the year, including all levels from 0 percent through 100 percent. As do other variable sources of electricity, wind plants typically produce in proportion to the resource available at the moment. Without buffering to smooth out variations, the power output of a wind plant is subject to wind speed, as the power of a solar electric plant is subject to momentary solar insolation.

The output of a solar plant is predictable under conditions of no cloud cover, but with the movement of clouds, output can vary on scales of minutes. Wind speed is predictable when influenced by large-scale, slow-moving weather, but with localized or fast-moving air masses, it becomes more unpredictable. Predictions of solar and wind conditions and electricity output are active areas of research.

New mediating technologies¹⁵ to smooth out power variations are in various stages of development. These include discrete energy storage systems, such as batteries, as well as programmable control of the kinetic, mechanical, and electrical energy within the turbine system. Such storage and control technologies are expected to play a larger role in electric system energy management over time.

In addition to the use of CFs in describing and understanding generators and the electric system, these factors can also be used in planning new generation, both in terms of physical planning and siting as well as financial planning.

Effect of Mitigation Measures

CFs are impacted when wind plants are taken offline or their outputs are curtailed, for either scheduled or unscheduled reasons. Plants may be subject to intentional restrictions of output, such as a requirement to not operate during certain months of the year as an environmental mitigation measure.

¹⁵ A mediating technology would reduce the variations in the output power with respect to variations in the input power. For example, it could make the electrical output of a generating plant less dependent on short-term variations in wind speed.

Each state or region of the United States that hosts wind plants is subject to particular mitigation conditions applied in those places. Laws and regulations at the federal, state, and local levels mean that power plants in each state may produce within the specific constraints applied to generation sites in those places. Nearly all power plant locations in the United States operate with specific mitigation conditions.

Some projects in California are restricted in the winter and are not allowed to operate for part of the first and fourth quarters of the year. These measures are often applied by a local government, such as a county, to mitigate for environmental impacts during the period of November through January or mid-February. These mitigation measures reduce output for three to three-and-one-half months per year. Sixteen projects in California are known to be affected by this type of restriction. These are in the Altamont WRA and total 366 MW in capacity. These projects mostly have many smaller turbines. Twelve of these projects with monthly data had no production in January, November, and December but did produce during the other months. This smaller group produced 19 GWh in October and 4 GWh in February. The February value would likely have been higher if mitigation in the first part of the month had not been in effect.

WPRS data are reported energy generation and include the effects of environmental mitigation and other factors that reduce the output of a generator. Data reporters are instructed to report the capacity of generators that are available to generate. The values presented here are not adjusted upward to predict the hypothetical situation of no mitigation. Both energy production and CFs presented here are thus lower in fact than would be realized with conditions of no mitigation.

In addition to curtailment for environmental mitigation, other factors could cause curtailment. The California ISO tracked curtailment due to system wide or local congestion in its Market Performance Report (California ISO, 2016) and tracked differences between actual production and forecast production. These types of curtailment were not visible in the WPRS data. At the end of 2014, 89 percent of in-state wind capacity was within the California ISO balancing area. Nationally, somewhat over 2 percent of wind power was curtailed in 2014 due to the combination of transmission inadequacy, generation limits, grid inflexibility and environmental restrictions (Wiser, 2015).

Range of Capacity Factors

CFs on an annual basis span a wide range, from near 0 percent up to very productive projects with annual capacity factors around 50 percent. This wide range is due to several factors. One is the presence of old turbines. Older equipment in parts of a project can reduce the number of turbines that are productive. Although an operator can implement repairs to older equipment when needed, the expense may not be justified by the terms of the existing power purchase agreement. This agreement typically ensures that the operator can continue to sell energy, but it may not provide an

incentive to modernize equipment. Agreement terms can range from 15 to 25 years (NREL, 2009).

Differences between energy prediction modeling during project design and siting and actual output when installed can also affect CFs. Such differences can occur due to factors such as insufficient reference sites that are close enough to the project or consequential differences in height between reference sites and installed equipment.

A common misconception regarding CFs is that a single number can characterize wind production over a large area, such as the United States or California. In fact, there is no generic CF, due to the importance of site-specific, technological, and seasonal factors. This is similar to the fact that there is no one-size-fits-all cost of energy generated. The relationship between CF and cost of energy is fundamental, as CF is a major component in calculating the cost of energy. No one CF can describe the variations due to climate zone and wind project technology and size across the state. The CF summarizes the amount of energy production with respect to turbine capacity. In a wind plant there is no fuel cost, unlike a gas plant, where the fuel is a major ongoing cost. A higher CF suggests stronger project revenue and shorter payback time. Wind CFs are potentially useful to a variety of interested parties, including financial analysts, modelers, system planners, and policy makers.

As a reference for those who may use wind information, the factors presented below are calculated using 2014 data. When using the tables, keep in mind the caveats described above regarding curtailment and mitigation measures.

Capacity Factors by Period

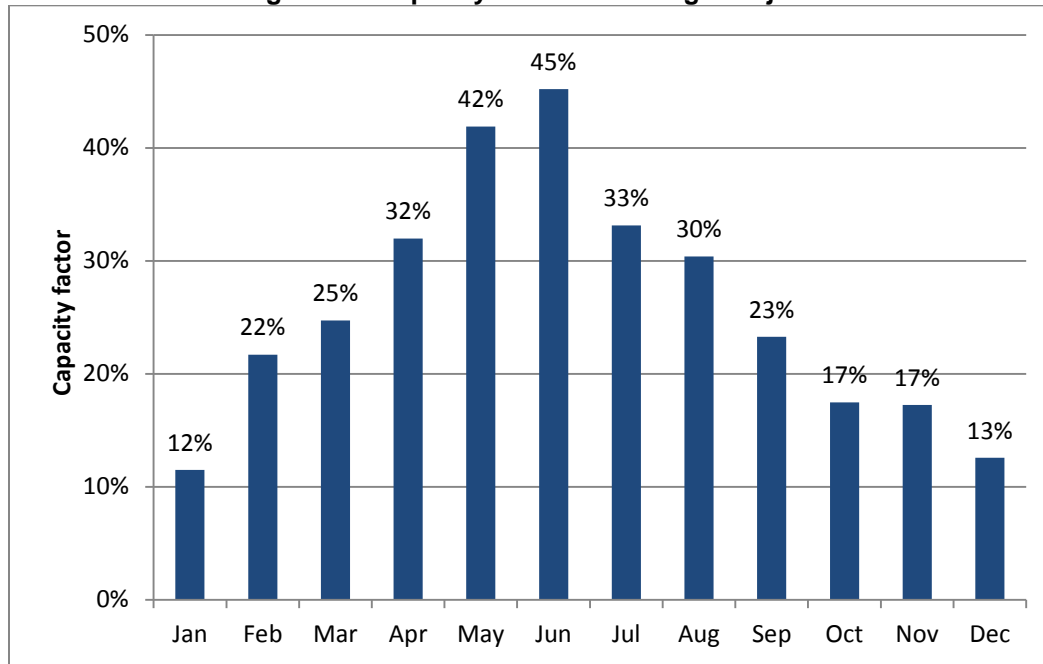
Factors are higher for large projects than for small, as larger ones typically include newer, more technologically advanced projects. Such projects can incorporate a number of electronic and mechanical systems optimized to increase output. CFs by month for each large plant during 2014 varied widely. These ranged from above 0.7 percent or 70 percent for some plants, during some summer months, to zero, primarily in the winter months. **Figure 17** shows CFs by month for all large plants combined. CFs range from 12 percent to 45 percent, with the highest months being June, May, and July. The lowest are January and February. As with energy production, the values for large projects are a good estimate of the values for all projects because of the preponderance of the large projects in the total. Because new projects tend to design for larger total capacities, the large-project CFs are also a better indicator of new project factors than the small-project CFs would be.

This pattern of distinctly peaking CFs in the summer months and lower factors in the winter months resembles patterns in some other regions of the United States, but it is unlike others (U.S. EIA, 2015). The northwestern United States shows two sequential peaks early in the summer and reaches lows in the winter. The other regions, including the upper Great Plains, lower Great Plains, Midwest, and New England, show strong

minima in the late summer to early fall. In this sense, the California wind fleet behaves like the Northwest fleet and unlike those in other regions.

Factors are shown with a precision of two significant figures. Three significant figures can be supported by the data reported, which contain at least three, and in many cases four to five figures. The data set contains a large amount of data, and minor inaccuracies in reporting are unlikely to affect the totals and overall calculations.

Figure 17: Capacity Factors for Large Projects



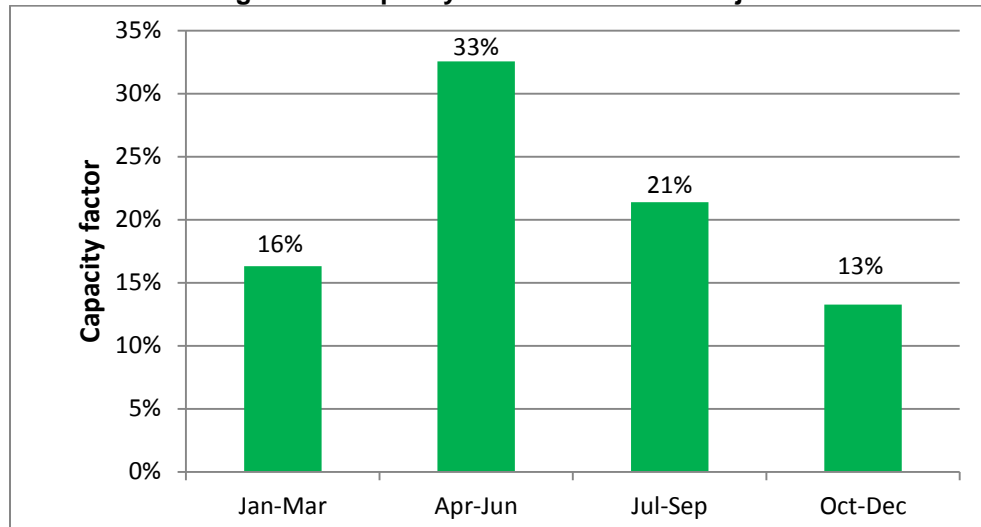
Source: Energy Commission, Supply Analysis Office.

For small projects, statewide CFs may be calculated by quarter. These factors ranged from 13 percent to 33 percent, as depicted in **Figure 18**. Factors were highest in the second quarter and lowest in the fourth quarter. Small projects typically include smaller, older turbines, which represent older technology and design features. For example, early turbines could not actively manage and optimize power, as current turbine technology allows.

Quarterly factors for all projects in the state show the same pattern as the small projects, with the highest quarter being the second quarter, and the fourth quarter being the lowest, as seen in **Figure 19**. The values are higher than for the small projects because of the effect of the large projects in the totals.

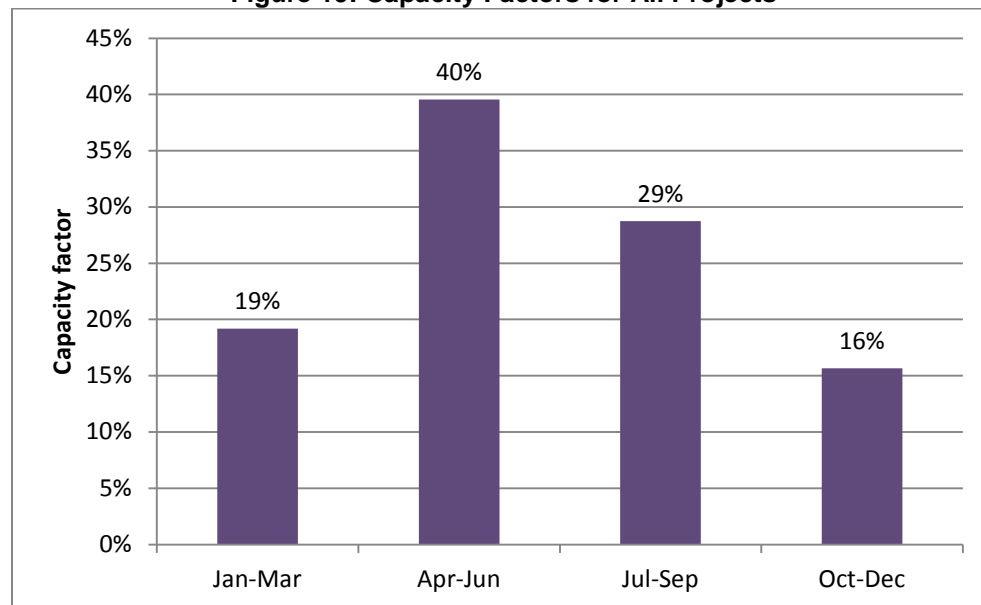
The factors include the full range of operating plant vintages in California. Newer plants can achieve higher factors because of better technology and more sophisticated siting and operating methods.

Figure 18: Capacity Factors for Small Projects



Source: Energy Commission, Supply Analysis Office.

Figure 19: Capacity Factors for All Projects



Source: Energy Commission, Supply Analysis Office.

Capacity Factors by Wind Resource Area

Factors are also calculated by WRA and quarter using data from all projects. These values are presented in **Table 2**.

CFs varied significantly among WRAs. The southernmost WRAs of East San Diego County, San Geronio, and Tehachapi had similar patterns, with peaks in the second quarter and significant decreases in the third quarter. The Pacheco area had the lowest values. The Altamont WRA trend had a similar shape to the Pacheco, and both peaked in the second quarter. The Solano area peaked in the third quarter, and it was unlike the others in that it peaked later in the year.

Table 2: Capacity Factor Values by Wind Resource Area and Quarter for All Projects

Quarter	East San Diego County	San Gorgonio	Tehachapi	Pacheco	Altamont	Solano
Jan-Mar	20%	19%	22%	5%	7%	14%
Apr-Jun	42%	41%	41%	26%	32%	39%
Jul-Sep	25%	30%	22%	25%	32%	48%
Oct-Dec	16%	15%	18%	4%	6%	12%

Source: Energy Commission, Supply Analysis Office.

The CFs for only the large projects are also computed, and the values are presented in **Table 3**. These factors may be taken as a good representation of the factors for the total of all projects.

Table 3: Capacity Factor Values by Month and Wind Resource Area for Large Projects

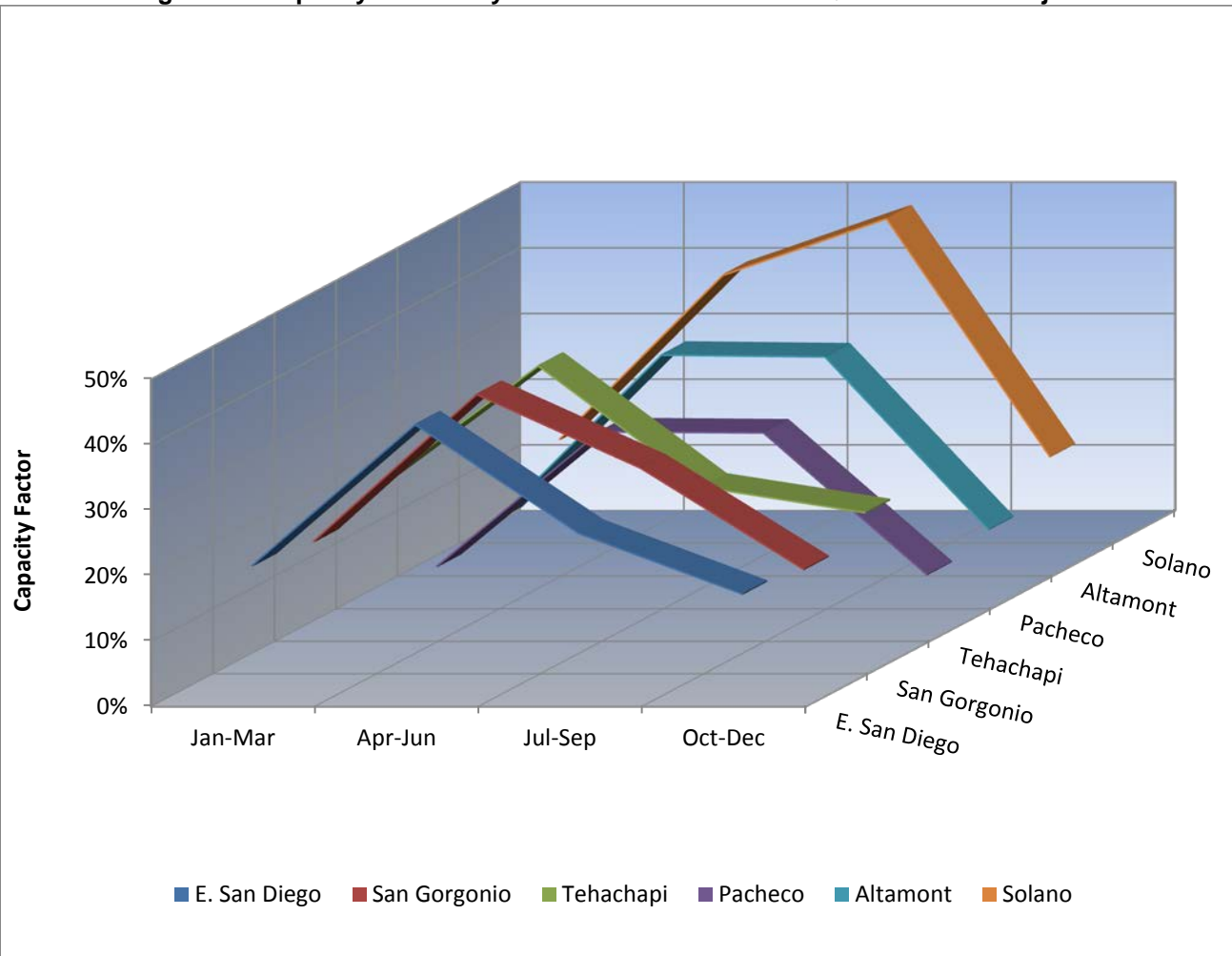
Month	East San Diego County	San Gorgonio	Tehachapi	Pacheco	Altamont	Solano
Jan	9%	8%	14%	2%	3%	8%
Feb	23%	22%	26%	4%	6%	14%
Mar	28%	26%	27%	8%	12%	21%
Apr	35%	32%	35%	16%	22%	26%
May	44%	43%	42%	28%	36%	42%
Jun	46%	49%	45%	32%	38%	50%
Jul	29%	37%	25%	32%	36%	54%
Aug	26%	31%	23%	26%	33%	51%
Sep	20%	22%	18%	17%	26%	39%
Oct	13%	18%	20%	6%	10%	15%
Nov	23%	21%	21%	3%	2%	7%
Dec	10%	6%	14%	2%	4%	14%

Source: Energy Commission, Supply Analysis Office.

Graphs of the CFs by WRA reveal the seasonal and geographic patterns in more detail, as shown in **Figure 20** and **Figure 21**. Here the similarity in the southern WRAs is evident. Also visible are the lower factors for Pacheco and the higher ones for Solano. With the monthly data, the fact that the Solano WRA peaked later in the year is evident. It peaked in July rather than June. In this way it matched electricity sales more closely than the other WRAs.

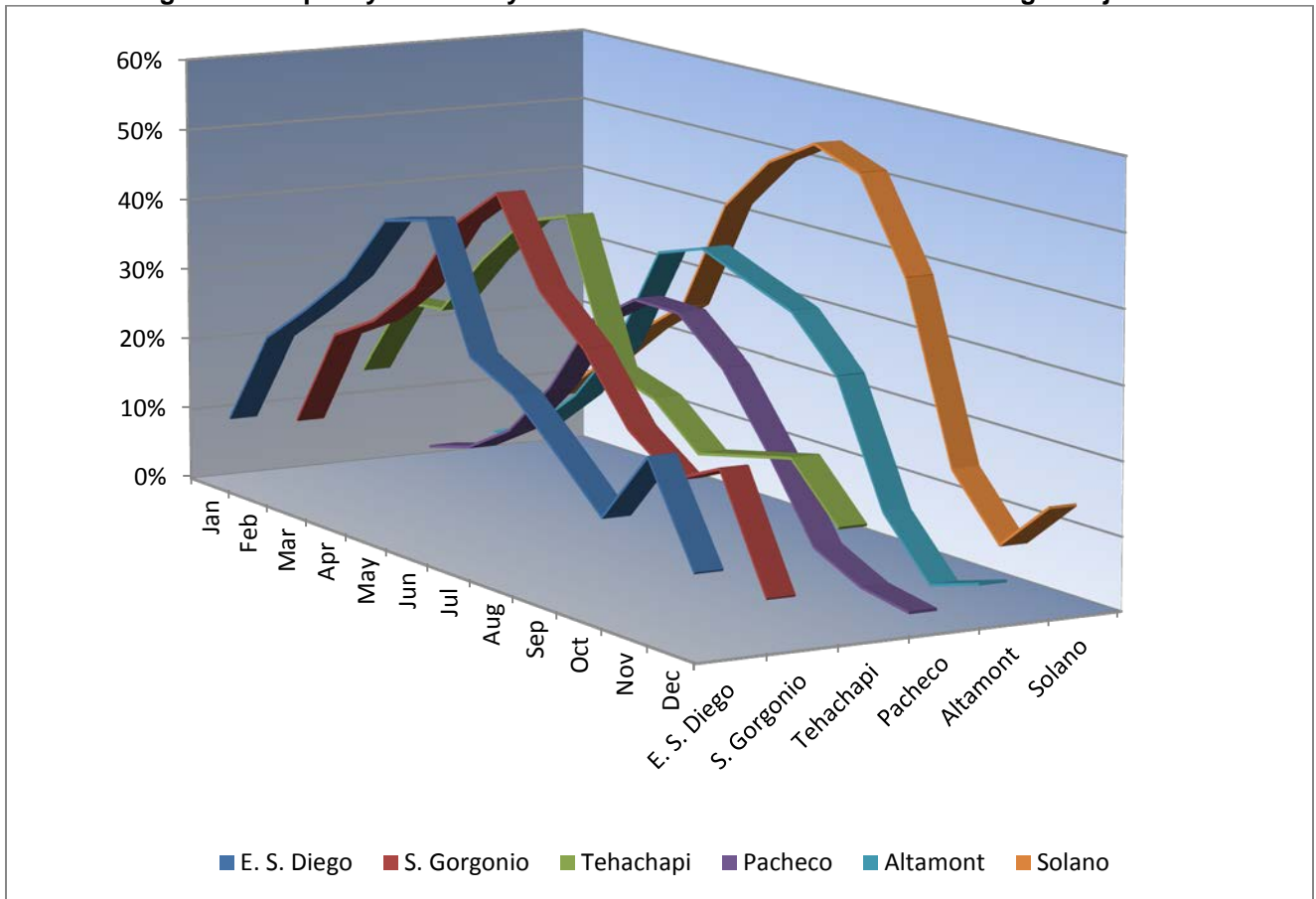
CFs of wind plants nationally attain 50 percent in excellent resource regions, and many projects achieve CFs of 30 percent–50 percent (AWEA-DS, 2015). The estimated average national CF for the year was 33.5 percent (WWPTO, 2015). Projects installed in the western states during 2012–2013 averaged 26.5 percent in CF

Figure 20: Capacity Factors by Wind Resource Area and Quarter for All Projects



Source: Energy Commission, Supply Analysis Office.

Figure 21: Capacity Factors by Month and Wind Resource Area for Large Projects



Source: Energy Commission, Supply Analysis Office.

CHAPTER 6:

Correlations of Generation

A set of CFs over a year for a wind plant describes the output profile for the plant. Many California plants have a low CF in the first quarter of the calendar year, increase to a maximum CF in early summer, and then decrease at the end of the year. An output profile of one wind plant may be more or less similar to the output profile of another plant. In addition to technology differences, plants at different locations experience different local weather and wind speeds.

By looking at the combination of profiles from two or more plants, previous studies have found that the total wind output is typically smoothed, as compared to the output from one plant alone. Summaries of this smoothing effect are presented in Louie, 2014; Reichenberger, 2014; and Fisher, 2013. One plant may generate at times when other plants are not generating, and its output is therefore complementary to output from the other plant. Plants that have complementary profiles can increase the constancy of total system energy. This is a benefit of geographic diversification.

California WRAs and wind farms are located over a wide area of the state. One could expect that pairs of WRAs or pairs of wind projects might show a wide range of similarity or difference, from very similar in output, to outputs peaking at quite different times of the year. Since most of the WPRS data are monthly data, there is an opportunity to test this expectation on a monthly basis. To analyze the similarity in profiles, staff used a statistical test to determine the correlation coefficients of pairs of profiles. This test quantifies the degree to which the capacity factor profiles of two WRAs or two wind projects are similar or different.

Staff analyzed the profiles from every pair of WRAs and, in a second phase, from every pair of large wind projects to determine correlation coefficients. The correlation coefficients determined indicate the strengths of the linear relationships between two sets of data, that is, between two sets of WRA CFs or two sets of wind project CFs.

Correlation coefficients can range from -1 to 1. A result of 1 indicates a perfect correlation in two data sets, and a WRA or wind project has a correlation coefficient of 1 when correlated to itself. A result of -1 indicates that two profiles are complementary. A zero result indicates neither a positive nor a negative correlation between the data sets. Appendix A explains the statistical test and the calculations in detail. The discussion below examines, first, the results of WRA-pair correlations and then of wind project-pair results.

Results of Wind Resource Area Correlations

Results of the analysis for WRAs are displayed in **Table 4**. WRAs that are in the same part of the state are placed adjacent in the table, and these are expected to have a stronger correlation coefficient than otherwise. A hypothesis is that wind farms that are closer to each other may have a stronger generation correlation than wind farms that are farther from each other. This could be expected, for example, when considering that areas closer together may experience more similar weather.

The results show that Altamont and Pacheco have the highest correlation coefficient with a value of 0.99. The lowest correlation coefficient was between Solano and Tehachapi with a value of 0.53. Even though Solano and Tehachapi have the lowest correlation coefficient value, they still have a strong positive relationship. The rest of the values are listed in **Table 4**. WRA names are arranged so that the WRAs are in sequence from north to south. Tehachapi generally showed the least amount of correlation to the other WRAs.

The correlation results generally support the hypothesis that WRAs closer to each other should have a higher correlation coefficient than WRAs that are farther apart. Altamont and Pacheco are both in Northern California. Solano and Tehachapi WRAs are in different parts of the state. Although Solano is on an inlet of the ocean near sea level, Tehachapi is in an inland mountainous area. Differences in elevation, topography, and distance from the coast may be expected to result in differences in energy profiles. Because the correlations are done using monthly data, they do not apply to shorter periods, such as hourly correlations over a single day. Correlation coefficients quantify the strength of correlations, but they do not describe causal mechanisms.

Table 4: Correlation Coefficients Between Wind Resource Areas

WRA	Solano	Altamont	Pacheco	Tehachapi	San Gorgonio	East San Diego County
Solano	1.00					
Altamont	0.98	1.00				
Pacheco	0.97	0.99	1.00			
Tehachapi	0.53	0.66	0.67	1.00		
San Gorgonio	0.79	0.87	0.89	0.90	1.00	
East San Diego County	0.64	0.75	0.76	0.97	0.96	1.00

Source: Energy Commission, Supply Analysis Office.

Results of Project Pair Correlations

As a further step in analysis, staff determined the correlation coefficients for each pair of large wind projects. The large projects have monthly data available. A high (or a low) correlation coefficient does not indicate that the CF is either high or low for either project. For example, one wind farm with low CFs that increase and decrease in the same months as another plant with higher CFs could still have a high correlation coefficient.

The calculations show that most pairs of plants have a correlation coefficient of 0.8 or higher. This indicates strong correlations in the generation output profiles of most pairs of plants. There are two plants, however, for which the correlation coefficients with most other projects are negative or close to zero.

Hatchet Ridge is not in any of the defined WRAs. It is near Burney in Northern California (Shasta County). The project had a median correlation coefficient of -0.35 with the other projects. The finding of weakly negative correlation coefficients with most other projects indicates that Hatchet Ridge has a generation profile that is negatively correlated with the generation profile of most other plants in the state. Hatchet Ridge production often moves in a different direction from that of other plants. This pattern is apparent in **Figure 22**.

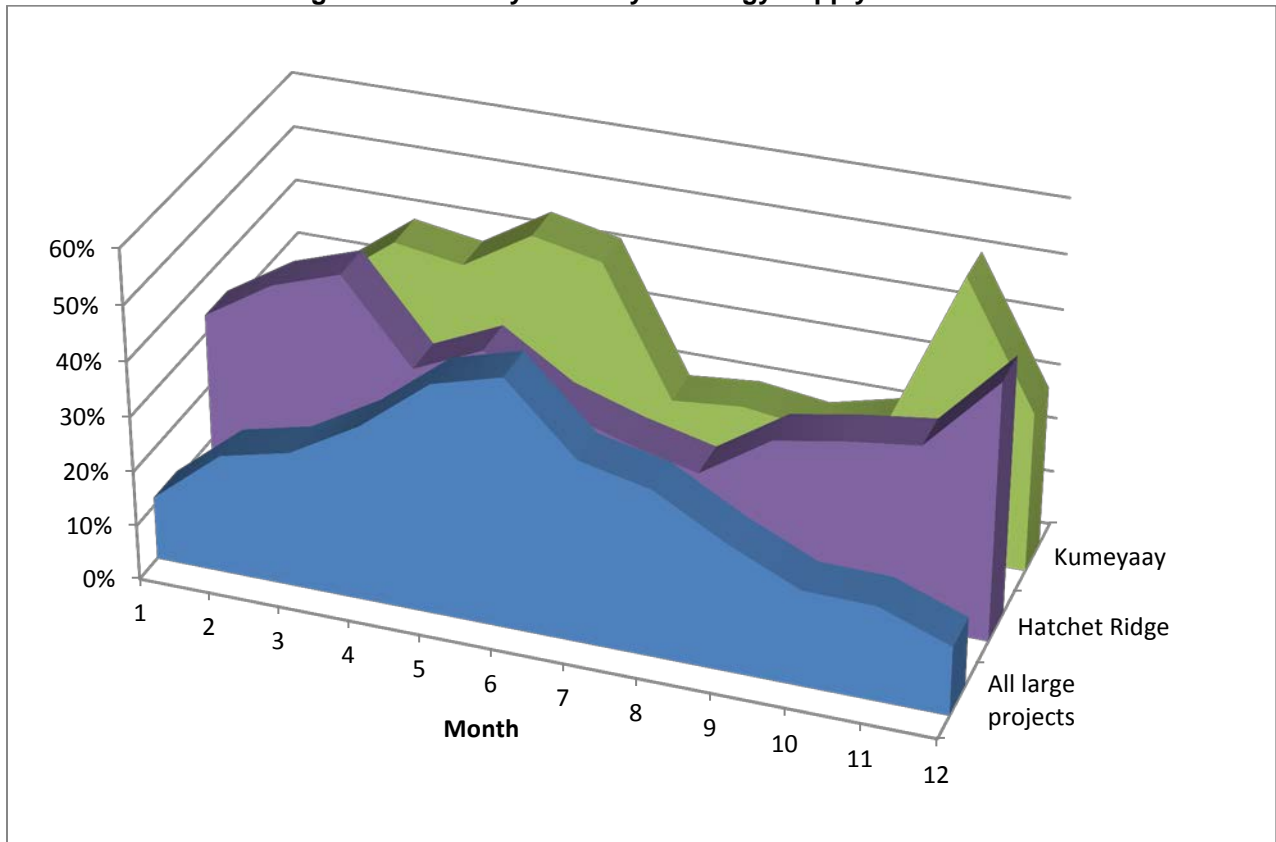
A difference in production like this provides an opportunity to the system in terms of the total supply of wind energy. When other wind generators are not producing as much, a project with a dissimilar output profile could provide complementary energy to the system and increase the diversity of the energy supply.

Another project that is less correlated is the Kumeyaay plant, located in the East San Diego County WRA. The project had a median correlation coefficient of 0.40 with the other projects. With most of the other projects, Kumeyaay had a range of correlation coefficients from weakly negative to weakly positive, indicating lack of correlation. However, when correlated to each wind farm located in the Tehachapi WRA, Kumeyaay had moderate positive correlation coefficient values ranging from 0.3 to 0.7, indicating somewhat of a correlation.

Kumeyaay had a similar generation profile to other wind farms in the spring, sharply decreased in the summer, and peaked again in November. The project reported experiencing considerable curtailment of production. Having a weaker correlation coefficient does not indicate that Kumeyaay was not productive. A weak correlation coefficient can be associated with CFs that are strong; in 2014, the project had strong CFs. The Kumeyaay project could also potentially provide wind energy to the system in months when other plants have lower production.

Figure 22 shows the diversity in yearly profiles of the Hatchet Ridge and Kumeyaay plants, along with the profile for all large plants. CFs are shown along the vertical axis. The graph illustrates the differences in generation profile for the two plants and the statewide total of all large plants.

Figure 22: Monthly Diversity in Energy Supply Profiles



Source: Energy Commission, Supply Analysis Office.

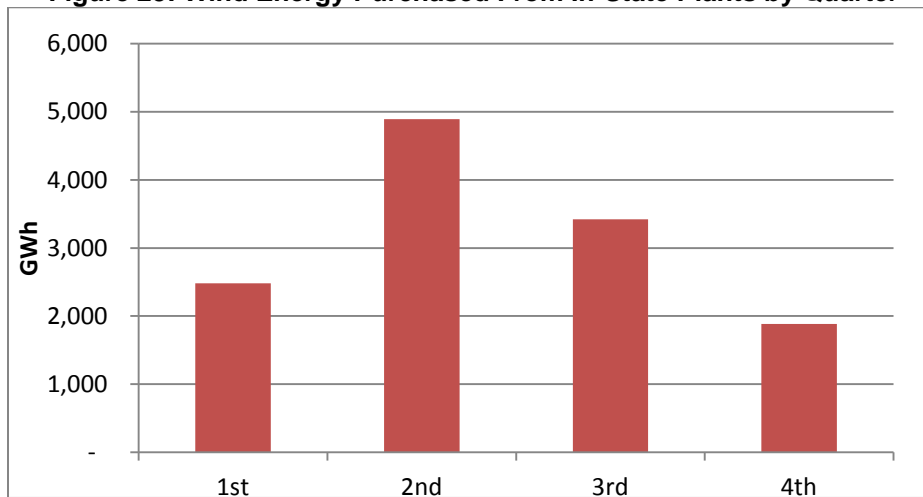
CHAPTER 7:

Energy Purchases

Purchasers of electricity from in-state wind plants of at least 1 MW are required to report purchased energy to the Energy Commission. These parties include both private and public organizations and may include POUs, IOUs, and ESPs. The purchases are a different data set than the generation data presented above, and they represent the other side of energy transactions. Purchasers report data using different forms, and they report less data than operators do. Regulations specify the data collected, but they do not require that purchaser reports be consistent with generation reports.

Data are reported as quarterly energy purchased. Reported purchases in 2014 totaled 12,682 GWh. These were highest in the second quarter, when 39 percent of the year's energy was purchased, and lowest in the fourth quarter, when 15 percent was purchased. Energy purchased is shown in **Figure 23**.

Figure 23: Wind Energy Purchased From In-State Plants by Quarter



Source: Energy Commission, Supply Analysis Office.

In 2014 the reported purchases were less than net generation by 392 GWh, which represents 3 percent. One reason for differences in reported energy between total generation and total purchases is that purchasers may not have clear breakdowns of energy source for energy purchased. In some cases, the purchase agreement provides for deliveries from a portfolio of sources. Actual energy delivered is at the seller's option, and there may be no specific energy source at a particular time. Therefore, the purchaser cannot be certain that the source is entirely from wind plants.

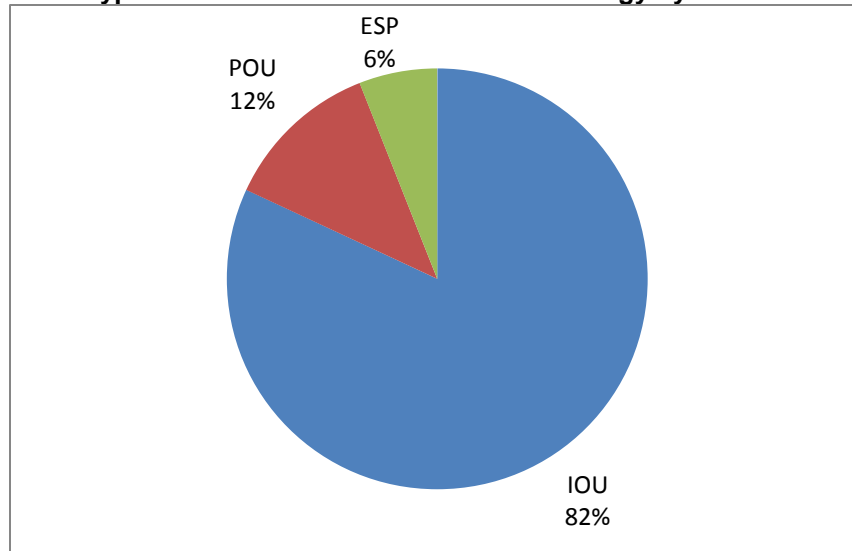
Also, some energy transactions are not settled until sometime after a trade is made, so reported values may be revised later. The WPRS includes procedures that allow

reporters to submit revised data for a period when they become aware of updated information. Human errors may also be a cause.

The Energy Commission does not measure the energy reported. Reporting parties state values they believe are correct. Submitted reports require a declaration under penalty of perjury that, to the best of their knowledge and belief, it is based on due diligence and is true, accurate, complete, and in compliance with regulations.

For some generators, the same party generates and purchases energy, and so the party participates in both roles in the market. The great majority of in-state wind energy was purchased by IOUs. POUs and ESPs purchased much smaller amounts, as depicted in Figure 24.

Figure 24: Type of Purchaser of California Wind Energy by Fraction of Energy



Source: Energy Commission, Supply Analysis Office.

Comparison to National Standings

For comparison to types of purchasers nationally, information on energy by purchaser type is not available. The closest comparison available is to the types of capacity purchasers. Capacity purchased nationally was made up of 49 percent by IOUs, 29 percent by POUs, and the rest by others.¹⁶ In national standing, several California utilities rank high in wind capacity purchases. These include 4 California utilities that rank in the top 10 in capacity under contract or owned (AWEA-DS, 2015):

- Southern California Edison (SCE)
- Pacific Gas and Electric Company (PG&E)
- San Diego Gas & Electric Company (SDG&E)
- Los Angeles Department of Water & Power (LADWP)

¹⁶ Hannah Hunt, American Wind Energy Association, email message to author, April 16, 2016.

Among only IOUs in the United States with wind capacity, SCE, PG&E, and SDG&E all rank in the top 10. Among only POUs in the United States with wind capacity, LADWP and Sacramento Municipal Utility District (SMUD) are in the top 10. WPRS data from operators show that SCE, PG&E, and SDG&E do not own wind plants in-state, but LADWP and SMUD do.

CHAPTER 8:

California Wind Generation in State, National, and World Context

California wind energy generation and purchases occur within the larger contexts of all energy in the state, wind energy in the United States and the world, and the wind resources in the state. To understand the place of wind energy within these contexts, information about each of them is presented below. This provides perspective on the WPRS data and analysis within these larger contexts.

Wind Energy and Capacity as a Portion of Total California Energy and Capacity

For comparison to all energy sources in California, data from the Quarterly Fuels and Energy Reports required by the California Code of Regulations, Title 20, Section 1304 are useful.¹⁷ The installed total in-state capacity was almost 80,000 MW in 2014, and wind capacity made up more than 7 percent of this. In-state energy generation was nearly 200,000 GWh in 2014, and wind energy made up almost 7 percent of this total. The in-state renewable generation totaled almost 45,000 GWh, and wind made up 29 percent of the renewable energy. Wind installed capacity grew from just under 4,000 MW in 2011 to nearly 6,000 MW in 2014.

Generation in the United States and World

Generation in national and international contexts is addressed below. The discussion includes information comparing California to United States and worldwide generation in both capacity and energy terms. Sections below cover:

- United States generation.
- Growth trends.
- Global generation.

United States Wind Capacity and Energy Generation

California wind capacity and energy can be placed in the contexts of U.S. wind capacity and energy. The capacity and energy contexts are discussed below in sequence.

United States Wind Capacity

Wind capacity in the United States totaled almost 66,000 MW as of the end of 2014 from a fleet of more than 48,000 turbines in more than 950 utility-scale projects (AWEA, 2015). Project capacities in the United States ranged to more than 800 MW, and the

¹⁷ CCR refers to the California Code of Regulations.

average size was trending upward (AWEA-DS, 2015). The average wind project built during 2011 was 58 MW, and the average in 2014 was 95 MW.

Other leading states in 2014 capacity are Texas (14,098 MW), and Iowa (5,688 MW) (AWEA, 2015). In recent years, California and Iowa have alternated between second and third places in capacity. California's neighboring states have smaller capacities in MW: Oregon under 3,200, Nevada under 200, and Arizona more than 200. California wind plants comprise roughly 9 percent of U.S. capacity. In number of turbines, California's fleet makes up about one-quarter of the nation's fleet.

Within the Western Electricity Coordinating Council (WECC) area, wind capacity was reported to be 24,300 MW in 2014 (WECC, 2015). Wind capacity has steadily increased in this area over the last decade.

Utility-scale U.S. capacity is installed in 39 states, across the West, central United States, and Northeast (AWEA, 2015). The Southeast region has the least capacity. Until recently that region lacked newer technology to reach the less accessible wind resources there, which require taller towers and larger rotors.

In other regions of the country, large wind resources are located over broad swaths of land with gradual elevation changes. Wind resources in California are often found near mountains, either in passes, such as at San Geronimo Pass, or near ridges, such as at Tehachapi. These differences in landforms and topographic slopes lead to more complexity in identifying good resources in California and result in having high-speed resources that occur in smaller zones. Some very good wind resources in the state are in areas far from existing WRAs. Many of these are in eastern California, scattered from the southeastern counties northward to the northeastern corner of the state.

Nationally, the leading project owners by installed MW include NextEra Energy Resources, Iberdrola Renewables, Berkshire Hathaway Energy, EDP Renewables North America LLC, and Invenergy (AWEA-DS, 2015). NextEra Energy is active as both an owner and an operator in California. Iberdrola Renewables is an operator.

United States Wind Energy Generation

U. S. wind plants generated a net of almost 182,000 GWh during 2014 (U.S. EIA, 2015), more than 4 percent of U.S. electricity. California plants produced more than 7 percent of U.S. wind energy production, following Texas and Iowa. Several states with smaller populations than California obtained one-quarter or more of their electricity from wind. These included states in the Midwest and Great Plains (WWPTO, 2015).

Growth Trends

In recent years, the pace of national wind development has been increasing. "Between 2008 and 2014, land-based wind accounted for 31 percent of all new generation capacity installed in the United States...." (Moniz, 2015, <http://energy.gov/articles/>

[secretary-moniz-announces-clean-energy-technologies-are-accelerating-us-marketplace](#)).

California added large capacity increments in 2010 through 2013.

National development of projects was expected to be strong in 2015 and 2016 (GWEC, 2015; WWPTO, 2015) with a fall-off expected in 2017 before a rebound starting in 2018. The federal Production Tax Credit and Investment Tax Credit are temporary credits subject to renewal by Congress, and uncertainties tied to the expirations and renewals of these tax credits have been responsible for most of the cyclical construction activity in the United States over the last decade. Most recently they expired at the end of 2014, followed a year later by extensions that will carry them through December 31, 2019 (DSIREUSA, 2015).

Another factor affecting the growth of wind energy both in California and nationwide is the price of natural gas. This competitive energy source significantly affects the demand for new wind energy projects. Where wind cost of energy falls below that of natural gas, wind generation becomes more attractive to utilities and other market participants, and developers can more easily finance new wind projects. California obtained 61 percent of its in-state electricity from natural gas during 2014. Price variation in the next few years may be expected to affect the growth in wind energy throughout the United States.

The cost of energy from wind projects nationally continued to fall in 2014. In the western states, the cost fell to the level last seen in 2006, declining from a high reached in 2010 (WWPTO, 2015). Whether this trend will continue depends on supply-and-demand forces in the turbine market, as well as larger economic factors and laws affecting the demand for renewable energy in the United States.

Growth in renewable energy sources is anticipated nationwide because of state and federal regulation, including the U.S. Environmental Protection Administration Clean Power Plan. The final rule, released in August 2015, requires states to reduce carbon emissions from existing power plants.¹⁸ The Clean Power Plan has been challenged in U.S. Supreme Court, and in an unusual move, the court stayed the rule until there is a resolution of the legal challenges that is expected later in 2016. Despite the stay, California is developing its state Clean Power Plan and expects to file with U.S. EPA late this year or early next year.

Global Generation

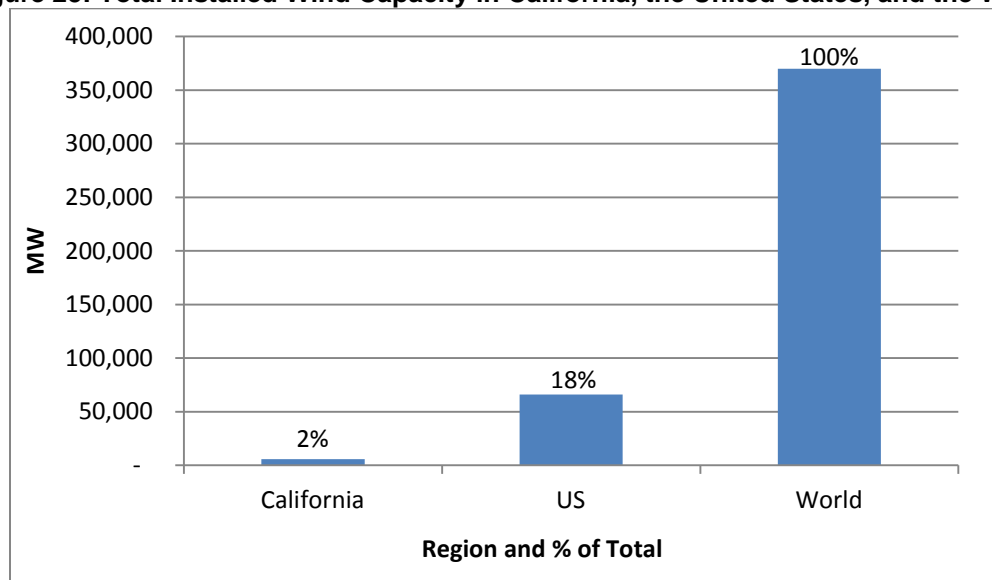
Global wind capacity was 370,000 MW from almost 270,000 turbines at the end of 2014 (GWEC, 2015). Wind energy was generated in 105 countries in 2014 (WWEA, 2015). California capacity represented roughly 2 percent of the global capacity and 4 percent of the total turbines.

¹⁸ Melissa Jones, California Energy Commission, Energy Assessments Division, email message to author, April 27, 2016.

China had more installed capacity with 115,000 MW than the United States (U.S. EIA, 2015). Grid capacity limitations within the country, however, prevented moving some of the energy to markets. The United States remained first in wind energy produced (AWEA-DS, 2015). Other leading countries for installed capacity include Germany, India, Spain, and the United Kingdom (WWPTO, 2015). A comparison of generating capacity in California, the United States, and world is shown in **Figure 25**, which places the capacities in context and shows both the magnitude of the capacities and the percentages of total world capacity. Although California had at one time a large share of world capacity, other states and countries have taken over the leading positions.

Wind energy production in 2014 was 599,000 GWh from International Energy Agency (IEA)-wind countries (IEA, 2015). Leading countries in production were the United States, China, Germany, Spain, and the United Kingdom (IEA, 2015). **Figure 26** depicts wind energy produced in 2014 and places the values in context, showing both the magnitude of the energies and the percentages of total world energy. California generated 2 percent of IEA-produced wind energy during the year.

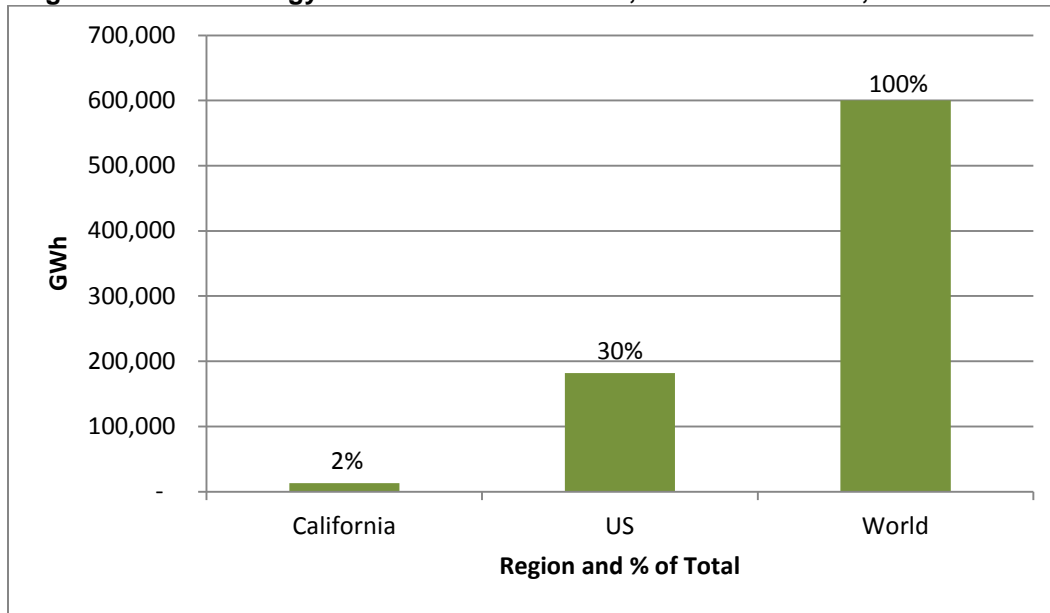
Figure 25: Total Installed Wind Capacity in California, the United States, and the World



Source: Energy Commission, AWEA, GWEC.

The United States obtained 4 percent of its electricity from wind in 2014 (IEA, 2015). This percentage compares to a range from 39 percent of national electricity in Denmark to 0.2 percent in Switzerland among the IEA countries. The United States ranks average among these countries. The wide variation from Denmark to Switzerland is likely due to differences in such factors as the proactive nature of Denmark's national energy policies in supporting renewable energy, as well as different landforms and related effects on wind speeds and construction costs. Other countries with high percentage contributions of wind to meeting their national electricity demand included Portugal, Spain, and Ireland. Wind power provided more than 3 percent of the world's electricity in 2014 (BTM Navigant, 2015).

Figure 26: Wind Energy Generation in California, the United States, and the World



Source: Energy Commission, U.S. EIA, IEA.

European nations continued their leadership in technology development and national policies to promote capacity. However, market opportunities for sales of generation and related equipment are shifting from developed countries toward developing ones. Europe should continue to lead in new technology in the near term, building on its well-established research and development and manufacturing base. European nations have offered greater incentives for renewables installation or production than the United States. These incentives increase and decrease as different political parties assume governance in those nations.

Installations continue to grow in Asia and India. More parts of the world are developing their resources, including South Africa, Uruguay, and Chile (BTM Navigant, 2015). Countries with high fossil fuel reserves and wealthier countries in the Middle East are sponsoring projects and international conferences to promote development.

Wind Energy Resource

The wind energy resource is the energy that is available for development using current and near-term technology. In this context, the resource is the net resource after taking into account land-use constraints, which reduce the gross resource to net values. Estimates of the wind energy resource over the land area of California have been made by the National Renewable Energy Laboratory (NREL) in a series of studies (see: <http://eere.energy.gov/>). NREL evaluates exclusion of potential areas for reasons of the environment, national defense, land use, and topography.

The state government has conducted a multi-year planning process known as the RETI that presents information about renewable resources of the state. The RETI process includes such items as assumed capacity factors, habitat areas, land-use planning data,

commercial interest data, and transmission data. The conclusions present information that can be used for further study when considering renewable energy potential in geographic areas for future renewable energy growth. RETI estimates do not calculate potential acres or capacities for energy sources.¹⁹

The California Wind Energy Association makes estimates of the current, near-term potential for further wind energy development. Taking into account current constraints on wind development in California, the association estimates that the near-term additional developable potential in the state is approximately 2,000 MW (Rader, 2016).

The ocean waters of California also hold wind resources, a portion of which are in shallow waters that can be accessed with technology with an operating history. This technology is in use in other countries and has been deployed with bottom-mounted foundations. Considering only the California waters accessible with shallow-water technology, there is 50,000 GWh per year of energy available (Dvorak, 2010). The estimate uses conservative assumptions for wind speed and is net of exclusion areas to account for wildlife, viewsheds, and shipping constraints.

Offshore resources are estimated to offer several advantages over onshore locations, including higher CFs, closer correspondence of generation profiles to demand, steadier winds than over land and in areas close to coastal areas with high populations, and a need for shorter transmission infrastructure when compared with most of California's WRAs.

An additional, much larger offshore wind resource is expected to become available as technology in the prototyping and development stages reaches the market. These are deep water resources, accessible using floating platforms. In addition to research and development in Europe and Asia, a 30 MW floating demonstration project is operating near Coos Bay, Oregon. That project is one of a group of U.S. DOE-funded projects to advance technologies that would be useful in opening additional offshore resources in the United States. Although the Oregon project is not specifically to advance California wind power, it is developing a floating system that would be useful at deep-water California wind resources (AWEA, 2015).

19 Eli Harland, California Energy Commission, Strategic Transmission Planning & Corridor Designation Office, email message to author, February 3, 2017.

CHAPTER 9:

2014 Data Analysis Summary

Some conclusions can be drawn either directly from the data collected in the WPRS or from staff analyses. These are grouped by topics below.

California is One of the Leaders in the United States

California is one of the leaders in wind power in the United States. Among a background of myriad sizes and types of turbines in use, new projects with newer and larger turbines continue to be installed in California. In addition, some older projects are being re-powered and more could be re-powered over time. Project locations include six established WRAs as well as other, more recently developed areas of the state. Terra-Gen is the leading operator in the state with a total capacity of more than 1,300 MW (22 percent of the total), and many owners are limited liability corporations or partnerships.

California wind energy accounted for more than 7 percent of total in-state electric capacity and energy produced, as well as 29 percent of the renewable in-state electricity generated in 2014. Also, wind energy makes up a significant share of Renewables Portfolio Standard energy in the state, and contributes to meeting clean-air and energy goals. Nationwide, California wind comprised 9 percent of U.S. wind capacity and more than 7 percent of U.S. wind energy.

Globally, California represents 2 percent of worldwide wind generation by both capacity and energy. Although California was a leader in wind technology development in the early years, today Europe leads in this area, with Asian countries advancing rapidly.

Why the Wind Performance Reporting System Was Revitalized

The status of wind energy is useful information for a wide variety of parties; data to provide insights are collected within the mandated WPRS program, which was revitalized in 2014. The WPRS data sets provide a snapshot of wind energy in California, covering generation and energy purchases from plants of at least 1 MW. Data time frames are either monthly or quarterly for generation, depending on plant size, and quarterly for purchases.

Wind Performance Reporting System Data is of High Quality

Energy Commission staff provided operators and purchasers extensive support during 2014, resolving many reporting questions and ensuring high-quality data. As a result, this data set on the status of California wind generation in the WPRS is of high quality.

Nevertheless, the turbine fleet is dynamic, changing every quarter as operators repower, terminate old projects, and start new ones. In addition, owners and operators of plants change. Additional reporting cycles should improve the data set.

2014 Wind Performance Reporting System Statistics

In-State Count of Plants and Total Capacity

As of end of 2014, 130 plants operated within the state, and two-thirds of them qualified as large, that is, 10 MW or larger. The total statewide capacity of the 130 plants was just under 5,900 MW as of the end of 2014, and the largest plant capacity was 265 MW. Overall, large plants comprised 97 percent of wind generation capacity. Many of the plants occupy a capacity range from of 10 MW to 200 MW, and generation from 10 GWh to more than 400 GWh.

Energy Generation and Purchases in 2014

The net energy produced during 2014 was more than 13,000 GWh with 97 percent of this by large plants. The most productive plant, Ocotillo Express in the East San Diego County WRA, produced more than 500 GWh. Production was highest in the second quarter and lowest in the fourth quarter. Production by large plants peaked in June, and they generated least in January.

Purchasers of wind energy reported purchasing almost 12,700 GWh during the year, which is 3 percent less than operators reported. This small difference can be explained by uncertainties in the sources of purchased energy, as well as by inconsistencies in reporting, as purchasers report separately from operators. Purchases were highest in the second quarter and lowest in the fourth quarter, which parallels the reported generation. Most energy was purchased by IOUs, and 4 California utilities rank in the top 10 nationally in the use of wind capacity.

Types of Turbines Used in California

California turbines span a range of vintages, from early, mechanically controlled machines of tens of kW in capacity, to modern electronically controlled machines of more than 3 MW in capacity. Two widely used turbine models include the Kenetech KCS 56-100 and the Vestas V90 3.0. Many older turbines were installed on lattice towers, but newer ones are installed on tubular towers, thereby significantly reducing the opportunities for use by avian species (birds), as well as reducing the potential for avian deaths.

The two most common turbine sizes are 100 kW, followed by 65 kW, exemplifying that much of the fleet represents older technology. Fewer modern, multi-MW sizes are installed. The largest turbines are 3.3 MW with a rotor diameter of 112 m. The leading countries of origin for California turbines are Denmark, followed by the United States, Germany, and Japan. This dominance of older technology represents an opportunity to modernize the fleet with resulting benefits in efficiency, grid compatibility, reduced

impacts on avian species, and increased renewable energy production. Current-market technology offers considerable advantages over much of the installed equipment in the state.

Plant Locations

WRAs are spread across the state from Solano in the north to East San Diego County in the south. The largest is Tehachapi in Kern County, with more than 4,000 turbines and more than 3,000 MW in capacity. It produced over half of the net energy during 2014. Projects continue to be developed in newer areas, such as East San Diego County and Shasta County. A new trend has been the installation of single and pairs of turbines at commercial or industrial sites outside existing WRAs; these small installations offset some of the energy consumed by the facility.

Plant Performance Using Capacity Factors

CFs span a very wide range from zero to more than 70 percent, depending on project and period of the year. A single, generic value for CF should not be used, as it overgeneralizes the range and variation in real CFs. The cost of energy has a strong dependence on CF, and in an analogous way, there is no generic cost of wind energy. Site-specific factors interact in complex ways to lead to CFs particular to each site and period. One of these factors is project size, with larger plants tending to have higher CFs than smaller plants.

Large-plant CF values can be taken as representing all plants in the state, due to the preponderance of the large plants in the whole fleet. For the large plants, monthly CFs range from 12 percent to 45 percent. Seasonal factors are also very important, with summer months having higher CFs at most plants, and winter months lower.

CFs are also affected by external influences, such as permit requirements. Some California plants CFs are reduced when they are required to be idle as mitigation for effects on avian species. For these plants, the mitigation results in a significant amount of lost energy. These plants represent a small fraction of all projects.

When viewed by WRA and quarter, CFs for all plants ranged up to 48 percent for the third quarter at Solano. This WRA peaked later than the other WRAs, which peaked in the second quarter. By WRA and month, the large-plant CFs peaked in July at Solano at 54 percent. Solano peaked closer to the month of highest electricity sales than did the other WRAs. In meeting growth in peak electricity demand, areas such as the Solano WRA could contribute more than WRAs that peak earlier in the year.

Production Patterns

Relationships between location of projects and energy output are also useful in understanding patterns of energy production across the state. Staff conducted an analysis to find the correlation coefficients (a measure of correlation) between the CFs over the year of the large projects. This was done both between the WRAs, as well as

between pairs of large projects. Results show that the Altamont and Pacheco WRAs are most strongly correlated. The weakest correlation was between Solano and Tehachapi. This supports the hypothesis that WRAs closer together should be more strongly correlated.

Correlations between all pairs of large projects revealed that most pairs of projects had strong positive correlations. Two exceptions were projects at the north and south ends of the state. These had negative or very weak correlations. This difference in generation profiles points to opportunity in diversification of the energy supply because plants in the north and south generate at somewhat different times than most other plants in the state. Additional plants at those locations could provide greater supply diversity to the state.

Future Potential

The net, land-based wind energy resources of California are substantial at the level of physical energy harvestable with current technology. However, a variety of constraints limit these to a smaller near-term developable potential. These constraints include environmental, land-use planning, commercial-interest, and transmission limitations.

Aside from the onshore potential, there is a shallow-water, net offshore resource of four times the 2014 energy generated, using Stanford University estimates. The technology to access a larger, deep-water resource is in development at an offshore wind project near Coos Bay, Oregon, as well as at sites in Europe and Asia. The untapped onshore and offshore wind resources could contribute to meeting increasing renewable energy goals.

Conclusion

The WPRS data set is a source of high-quality data and information for wind energy in California, including capacity as well as energy generated and purchased. Data reporters legally attest to the accuracy, completeness and regulatory compliance of data they submit, and they and staff have devoted significant effort to ensure that reporting is comprehensive.

ACRONYMS

ACRONYM	DEFINITION
AWEA	American Wind Energy Association
California ISO	California Independent System Operator
CCR	California Code of Regulations
CF	Capacity factor
CPUC	California Public Utilities Commission
EERE	Energy Efficiency & Renewable Energy Office
ESP	Energy service provider
GE	General Electric
GWEC	Global Wind Energy Council
GWh	Gigawatt-hour
IEA	International Energy Agency
IOU	Investor-owned utility
kW	Kilowatt
kW/m ²	Kilowatt per meter squared
kWh	Kilowatt-hour
kWh/m ²	Kilowatt-hour per meter squared
LADWP	Los Angeles Department of Water and Power
M	Meter
M/S	Meters per second
MW	Megawatt
MWh	Megawatt-hour
NREL	National Renewable Energy Laboratory
PDF	Portable document format
PG&E	Pacific Gas and Electric Company
POU	Publicly owned utility
RETI	Renewable Energy Transmission Initiative
RPM	Revolutions per minute
RPS	Renewables Portfolio Standard
SCE	Southern California Edison Company
SDG&E	San Diego Gas & Electric Company
SMUD	Sacramento Municipal Utility District
U.S. DOE	United States Department of Energy
U.S. EIA	United States Energy Information Administration
U.S. EPA	United States Environmental Protection Agency
WECC	Western Electricity Coordinating Council
WPRS	Wind Performance Reporting System
WRA	Wind resource area
WWEA	World Wind Energy Association
WWPTO	Wind and Water Power Technologies Office

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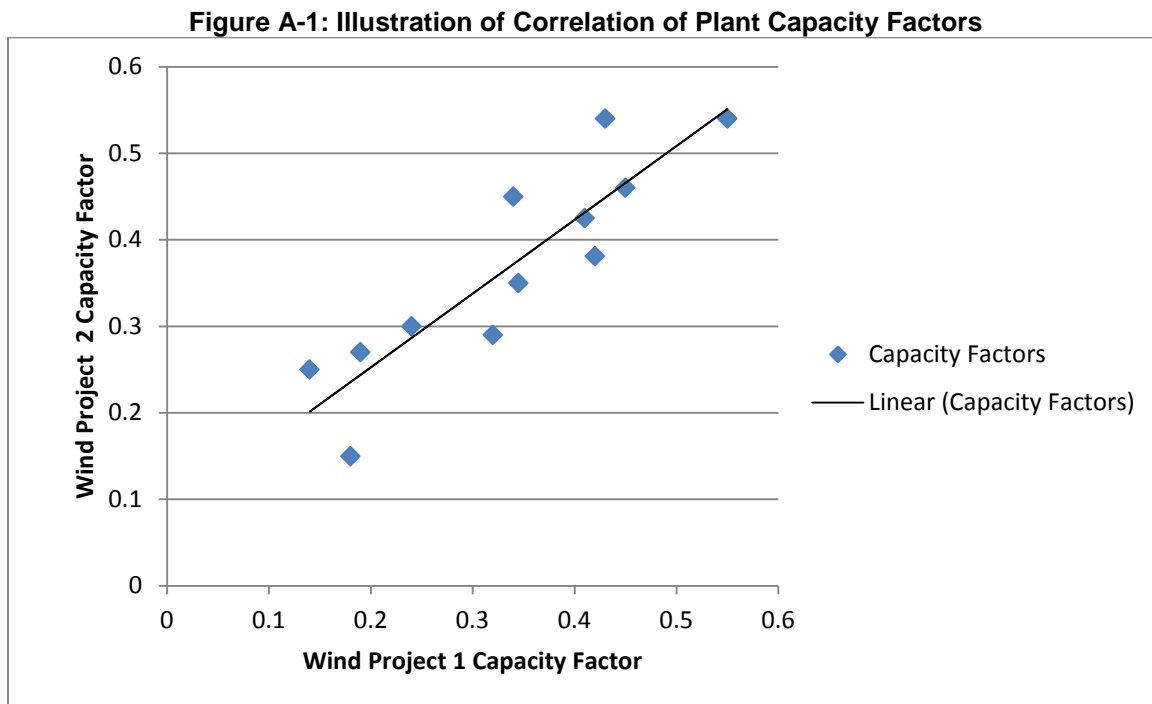
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APPENDIX A:

Correlation Coefficient Method

A correlation coefficient is a way to determine the strength of the linear relationship between two sets of data, which in this case is CF data.

Figure A-1 is a hypothetical illustration of what CF data sets of two wind plants would look like if they were graphed. The points in this graph describe an increasing trend in which when the CF for project one is greater, the CF for project two is also greater. These two projects have a similar output profile. That is, they have high production during the same times of the year. The trend in **Figure A-1** shows a strong positive relationship between the profiles of the two wind farms, with a correlation coefficient of 0.89. Because there are 12 monthly CF values for each wind project, there are 24 data values used in the correlation coefficient calculation.



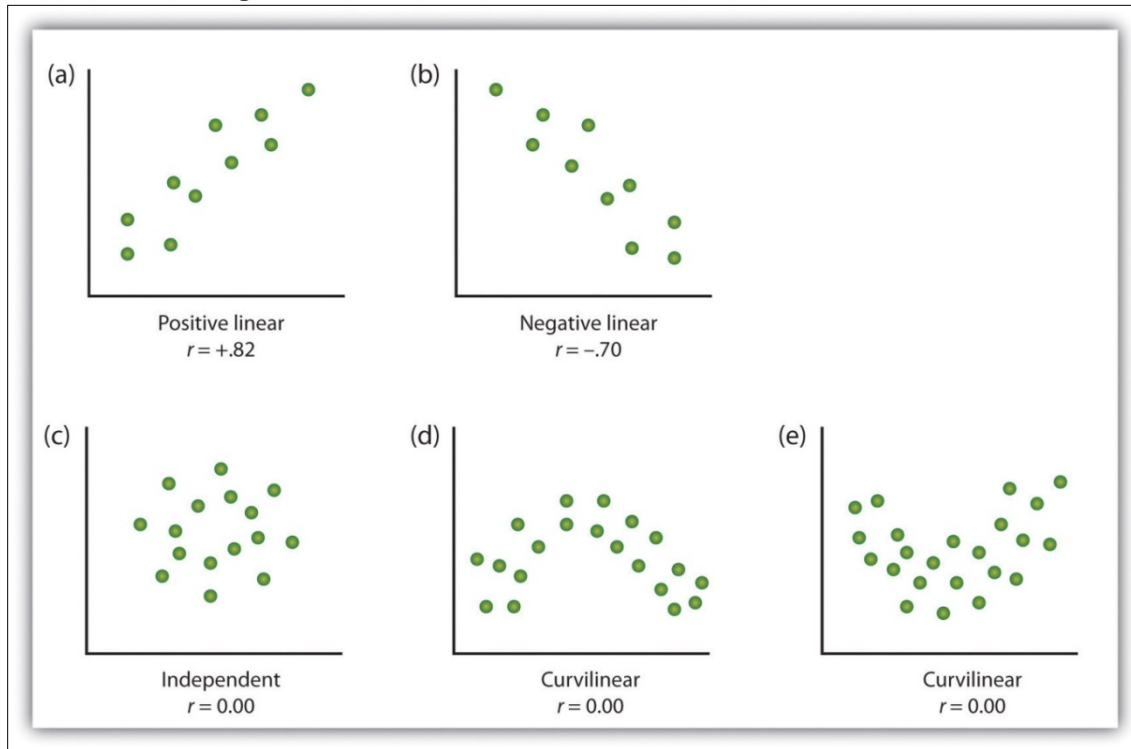
Source: Energy Commission, Supply Analysis Office.

Pearson Correlation Coefficient

The Pearson correlation coefficient measures the strength of the linear relationship between two variables X and Y of two sets of data. Although there are several methods to test the strength of the relationship between different wind projects or WRAs, staff chose the Pearson correlation coefficient because it is a straightforward and simple method. The method was applied to large wind projects and to the WRAs. This can be visualized on a

scatter plot graph. Refer to **Figure A-2** for a visual illustration of possible scatter plots. The primary interest is whether there are strong relationships between the CFs of pairs of wind projects and WRAs.

Figure A-2: Illustration of Correlation Coefficient Patterns



Source: See http://catalog.flatworldknowledge.com/bookhub/127?e=stangor-ch02_s02.

The correlation coefficient is a value between -1 and 1 denoted as r . If $r = 0$, there is no linear association between the two sets of data. Refer to the graphs (c), (d), and (e) in **Figure A-2**. Two sets of data may have a perfect non-linear relationship (graph [d] and [e]) and have a correlation coefficient of 0. The correlation coefficient measures only the strength of the linear relationship. If $r = 1$, the two measures have a perfect positive linear relationship (Weisstein, 2015). In other words, both data sets would fall on the same straight line. If $r = -1$, the two sets of data have a perfect negative linear relationship. The two datasets would be moving in opposite directions at the same time.

In practical terms, if $r = -1$, the CFs of one wind project or WRA would be increasing while the CFs of the other are decreasing. This negative correlation would indicate that the output of one plant is complementary to that of another plant. This conclusion would apply on a monthly basis here because the large-plant data is monthly.

The two cases of interest are that either the projects have a positive linear relationship or a negative linear relationship. The graphs (a) and (b) are close to a perfect linear relationship as shown in **Figure A-2**. These linear relationships can show wind projects (or WRAs) increasing in generation together or decreasing in generation together.

Correlation coefficients as strong as 1 or -1 are very rare. Although there is no absolute interpretation of correlation coefficient values, generally values from -1 to -.5 or from 0.5 to 1 are considered high correlation coefficients, indicating a strong linear relationship (Andale, 2012). Values from -0.5 to 0.5 are considered to be a low-correlation coefficient, indicating a weak linear relationship. This interpretation of correlation coefficients was used when interpreting the resulting correlation coefficients. Staff found each correlation coefficient using the Pearson correlation coefficient formula:

$$CC = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{\sum \sqrt{(x_i - \mu_x)^2} \sum \sqrt{(y_i - \mu_y)^2}}$$

The variables are as follows:

- x_i is the capacity factor for the month for WP 1 (or WRA 1)
- μ_x is the average capacity factor for the year for WP 1 (or WRA 1)
- y_i is the capacity factor for the month for WP 2 (or WRA 2)
- μ_y is the average capacity factor for the year for WP 2 (WRA 2)

Note: WP = Wind project

WRA = Wind resource area

The calculations were done using “R Software,” Version 3.2.2, and Microsoft Excel© was also used as a verification of the calculations.²⁰ Differences in results between the two programs were typically negligible, for example, at the level of 1 part in 10,000. Differences of this size are not significant for this purpose.

As a check for possible nonlinear correlations, staff also selected the project pairs that had the weakest linear correlation coefficient values. By graphing the CF values on scatter plots, the distribution of points could be inspected. None of these plots showed a significant nonlinear correlation.

²⁰ R Software, Version 3.2.2 R is a free software environment for statistical computing and graphics. See <https://www.r-project.org/> for more information.